Agro-Environmental Impact Assessment and Farm Management

Agro-Environmental Impact Assessment - LCA

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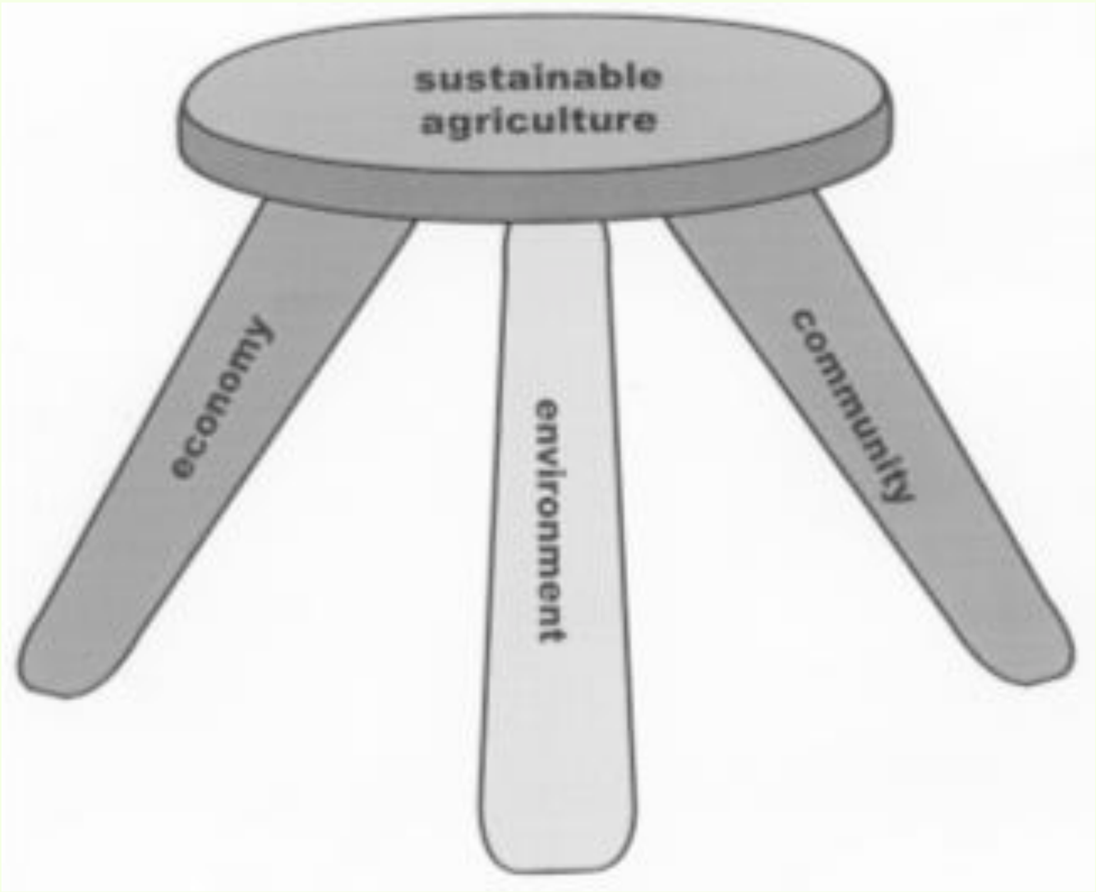
Sustainable Development

The use of ecosystems and their resources in a manner that satisfies current needs without compromising the ability of future generations to meet their needs.

Definition of sustainable agriculture

- "A sustainable agriculture is one that, over the long-term, enhances environmental quality and the resource base on which agriculture depends; provides for basic human food and fiber needs; is economically viable and enhances the quality of life for farmers and society as a whole" (FAO, 1989).

Sustainable Agriculture Goals



- Environmental Health
- Economic Profitability
- Social and Economic Equity

Sustainable agriculture as a set of practices.

An approved set of “sustainable practices” is defined.
Practices are chosen by their ability to maintain production while limiting environmental impact.

- These often include:

- Biological or organic pest controls
- Organic Soil Amendments
- Low stocking rates for animals
- Integrated Pest Management
- Conservation Tillage Practices

A Rapid, Farmer-Friendly Agroecological Method to Estimate Soil Quality and Crop Health in Vineyard Systems

A practical methodology to rapidly assess the soil quality and crop health of vineyard systems using simple indicators.

The indicators were selected because:

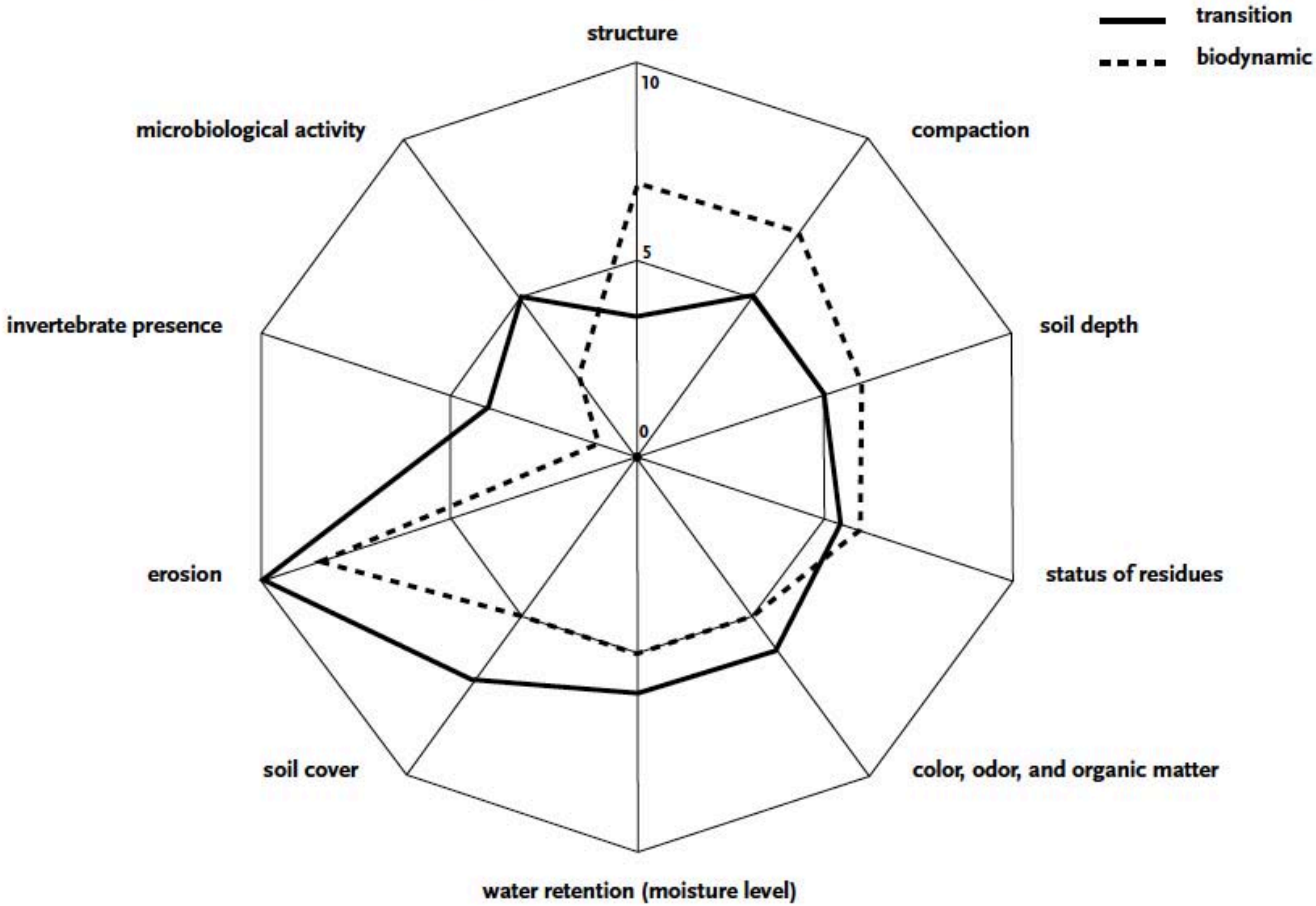
- they are easy to use by farmers
- they are relatively precise and easy to interpret
- they are practical for making new management decisions
- they are sensitive enough to reflect environmental changes and the effects of management practices on the soil and the crop
- they possess the capability of integrating physical, chemical and biological properties of the soil
- they can relate to ecosystem processes, for example the relationship between plant diversity and pest population stability and/or disease incidence

Indicators of soil quality	Established value	Characteristics
Structure	1	Loose, powdery soil without visible aggregates
	5	Few aggregates that break with little pressure
	10	Well-formed aggregates – difficult to break
Compaction	1	Compacted soil, flag bends readily
	5	Thin compacted layer, some restrictions to a penetrating wire
	10	No compaction, flag can penetrate all the way into the soil
Soil depth	1	Exposed subsoil
	5	Thin superficial soil
	10	Superficial soil (> 10 cm)
Status of residues	1	Slowly decomposing organic residues
	5	Presence of last year's decomposing residues
	10	Residues in various stages of decomposition, most residues well-decomposed
Color, odor, and organic matter	1	Pale, chemical odor, and no presence of humus
	5	Light brown, odorless, and some presence of humus
	10	Dark brown, fresh odor, and abundant humus
Water retention (moisture level after irrigation or rain)	1	Dry soil, does not hold water
	5	Limited moisture level available for short time
	10	Reasonable moisture level for a reasonable period of time
Soil cover	1	Bare soil
	5	Less than 50% soil covered by residues or live cover
	10	More than 50% soil covered by residues or live cover
Erosion	1	Severe erosion, presence of small gullies
	5	Evident, but low erosion signs
	10	No visible signs of erosion
Presence of invertebrates	1	No signs of invertebrate presence or activity
	5	A few earthworms and arthropods present
	10	Abundant presence of invertebrate organisms
Microbiological activity	1	Very little effervescence after application of water peroxide
	5	Light to medium effervescence
	10	Abundant effervescence

Indicators of crop health	Established value	Characteristics
Appearance	1	Chlorotic, discolored foliage with deficiency signs
	5	Light green foliage with some discoloring
	10	Dark green foliage, no signs of deficiency
Crop growth	1	Uneven stand; short and thin branches; limited new growth
	5	Denser. but not uniform stand; thicker branches; some new growth
	10	Abundant branches and foliage; vigorous growth
Disease incidence	1	Susceptible, more than 50% of plants with damaged leaves and/or fruits
	5	Between 25–45% plants with damage
	10	Resistant, with less than 20% of plants with light damage
Insect pest incidence	1	More than 15 leafhopper nymphs per leaf, or more than 85% damaged leaves
	5	Between 5–14 leafhopper nymphs per leaf, or 30–40% damaged leaves
	10	Less than 5 leafhopper nymphs per leaf, and less than 30% damaged leave
Natural enemy abundance and diversity	1	No presence of predators/parasitic wasps detected in 50 random leaf sampled
	5	At least one individual of one or two beneficial species
	10	At least two individuals of one or two beneficial species
Weed competition and pressure	1	Crops stressed, overwhelmed by weeds
	5	Medium presence of weeds, some level of competition
	10	Vigorous crop, overcomes weeds
Actual or potential yield	1	Low in relation to local average
	5	Medium, acceptable
	10	Good or high
Vegetational diversity	1	Monoculture
	5	A few weeds present or uneven cover crop
	10	With dense cover crop or weedy background
Natural surrounding vegetation	1	Surrounded by other crops, no natural vegetation
	5	Adjacent to natural vegetation on at least one side
	10	Surrounded by natural vegetation on at least two sides
Management system	1	Conventional
	5	In transition to organic with IPM or input substitution
	10	Organic, diversified with low external biological inputs

	Indicators	Benziger vineyard (organic/biodynamic)	Cain vineyard (in transition)
Soil quality	Structure	7	3.5
	Compaction	7	5
	Soil depth	6	5
	Status of residues	6	5.5
	Color, odor, and organic matter	5	6
	Water retention (moisture level)	5	6
	Soil cover	5	7
	Erosion	8.5	10
	Invertebrate presence	1	4
	Microbiological activity	2.5	5
	Average of soil quality	**5.3**	**5.7**
Crop health	Appearance	8.5	6.5
	Crop growth	8.5	8
	Disiease incidence	9	10
	Insect pest balance	9.5	10
	Natural enemy abundance & diversity	1.5	2
	Weed competition & pressure	9	10
	Actual or potential yield	8	6
	Vegetational diversity	4	3.5
	Natural surrounding vegetation	9	8
	Management system	7	4
	Average of crop health	**7.4**	**6.8**

Figure 2. Amoeba representing the soil quality status of two vineyard systems (Cain – transitioning to organic, and Benziger – biodynamic) in northern California.



Life Cycle Assessment

- A product's life cycle starts when raw materials are extracted from the earth, followed by manufacturing, transport and use, and ends with waste management including recycling and final disposal. At every stage of the life cycle there are emissions and consumption of resources. The environmental impacts from the entire life cycle of products and services need to be addressed. To do this, life cycle thinking is required.

Life Cycle Assessment

The International Organization for Standardization (ISO), a world-wide federation of national standards bodies, has standardized this framework within the ISO 14040, 1997 series on LCA.

Life cycle thinking and Life Cycle Assessment...

- can help to avoid solving one problem while creating another.
- can help reduce the quantities of waste, associated environmental and health impacts, and the indirect costs associated with these impacts that are borne by society.
- can be a support in, but not a replacement for, decision making

Main issues in LCA

- The context of the study
  - What decision is to be informed by the study ?
  - What is the scale of the different options ?
- Environmental impacts of concern
  - What impacts are of concern - What impacts are not important ?
  - How important is one impact compared to another ?
- The design of the scenarios and technical system models
  - Accounting model or Consequence model ?
  - Marginal changes or Large-scale changes (“affecting infrastructure”) ?
  - Allocation (Distribution of impacts in processes providing several functions) ?
- Data for processes
  - Specific, Average, Marginal, Typical, Future ?
  - Availability ?

Life Cycle Assessment

- Life Cycle Assessment (LCA) is a tool for the systematic evaluation of the environmental aspects of a product or service system through all stages of its life cycle. LCA provides an adequate instrument for environmental decision support. Life cycle assessment has proven to be a valuable tool to document the environmental considerations that need to be part of decision-making towards sustainability.

How to do LCA

1. Determine scope and system boundaries
   - functional unit
   - life-cycle stages
   - define “unit processes”
2. Data collection
3. Analysis of inputs and outputs
4. Assessment of numerous environmental issues
5. Interpretation

LCA in Agriculture

Life-cycle analysis is a technique that assesses the environmental impacts throughout the entire farming system.

Each step of the process is considered including the inputs of materials, on-farm activities plus the use of the end products and disposal of waste materials.

Outputs can be expressed per unit of production or land used, reflecting the dual nature of farming, production and occupancy of land.

Usually cradle-to-farm gate analysis instead of a cradle-to-grave

LCA consists of four phases:

(1) Goal and scope definition, in which the intended application as well as the extent of the study has to be clearly exposed.

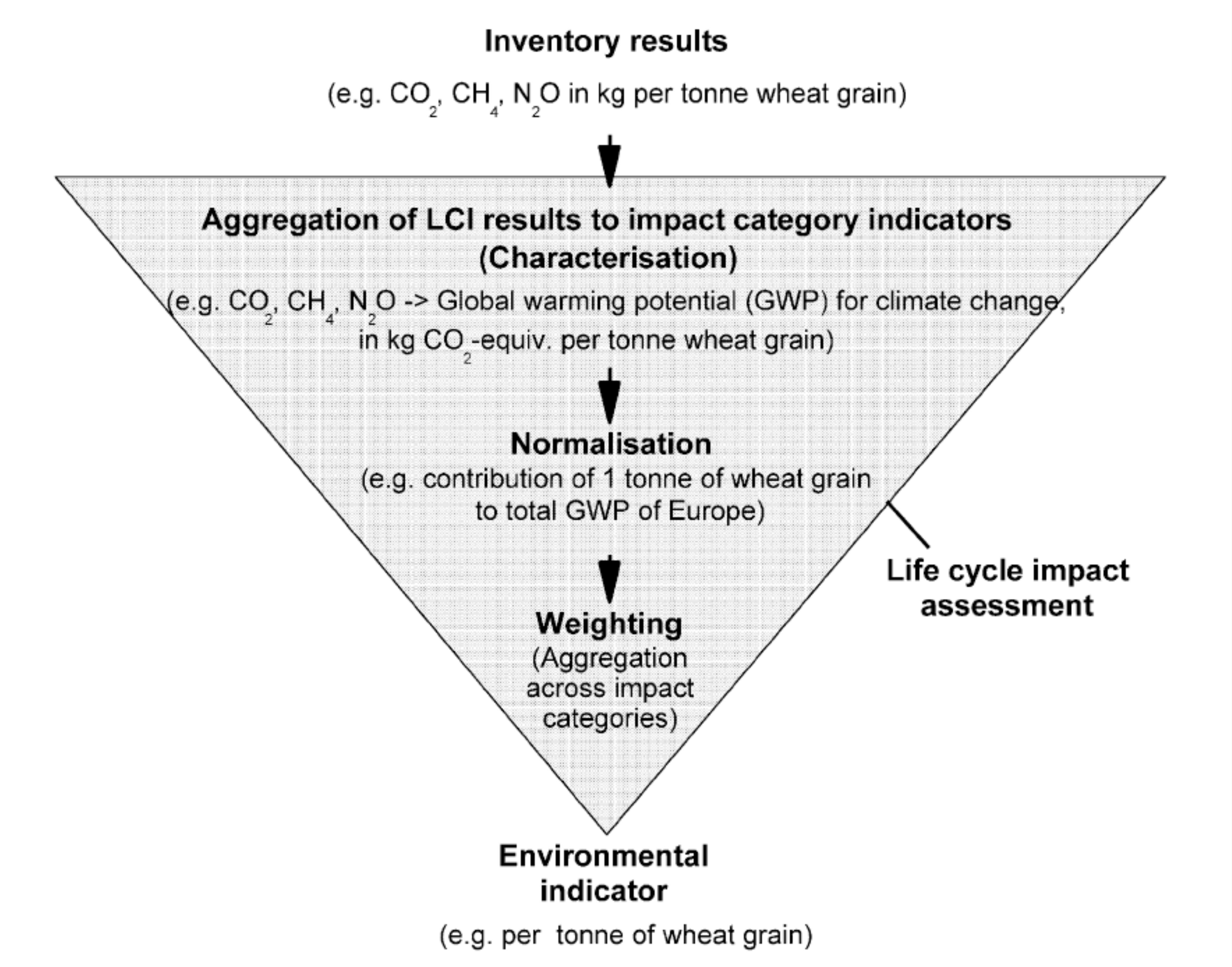
- *Functional unit*
- *System boundaries*

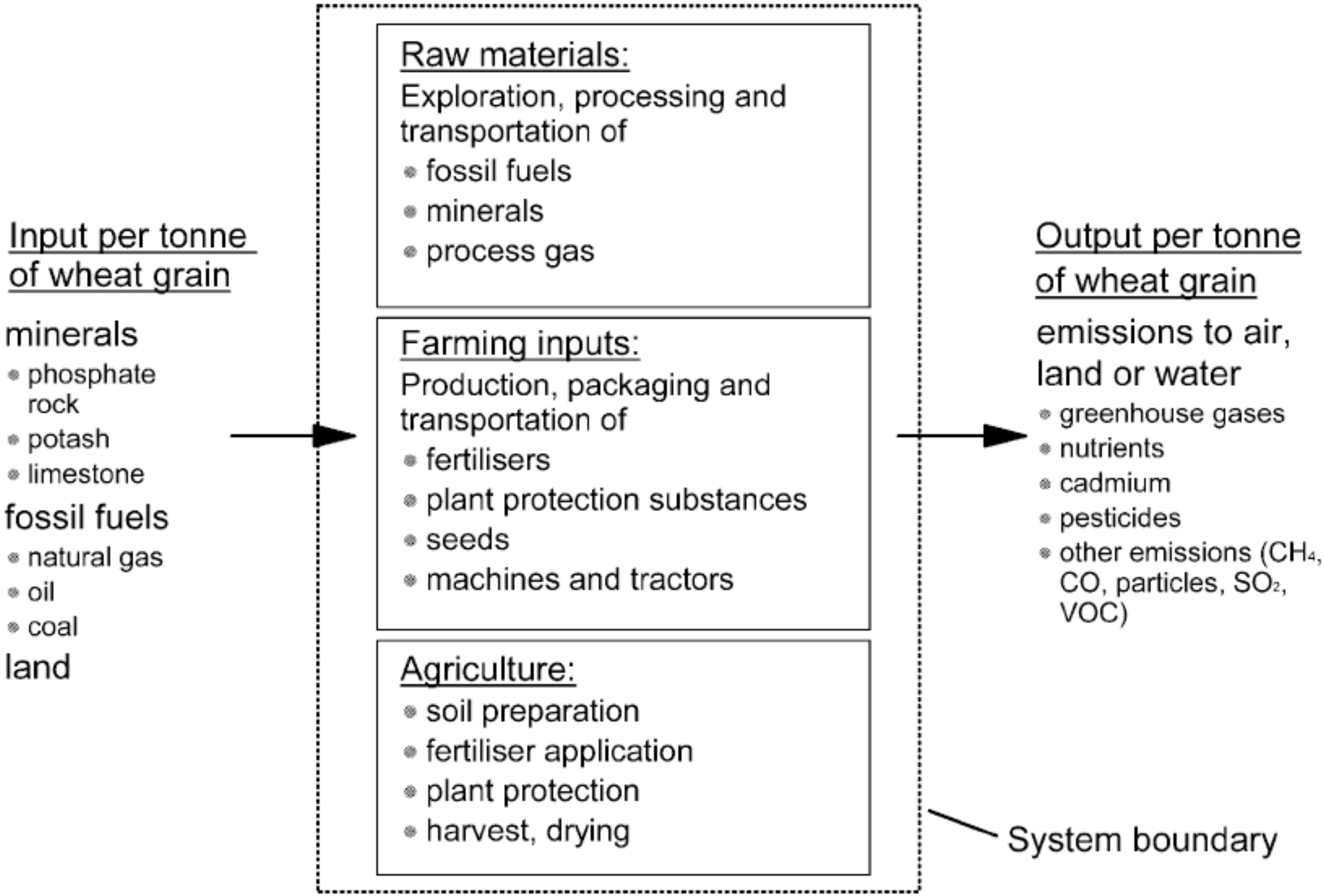
(2) Inventory analysis (LCI), where information about the product system is gathered and relevant inputs and outputs are quantified.

(3) Impact assessment (LCIA), which converts the flows from the inventory into indicators related to the potential associated impacts.

(4) Interpretation, where the findings of the two previous steps are combined and evaluated to meet the previously defined goals of the study.

The general life cycle impact assessment procedure





System boundary, relevant in- and outputs, and functional unit of a wheat production system

Indicators of farm (agroecosystem) sustainability.

Such an indicators would enable:

- Policy makers to support sustainable farm operations through legislation.
- Consumers to support sustainable farm operations through purchases.
- Farmers to analyze and address the sustainability of their own operations.

The crafting of indicators:

- According to Costanza and Patten(1995:194), "What passes as definitions of sustainability are often predictions of actions taken today that one hopes will lead to sustainability."
- The same is true of indicators.

- Any present measurement is at best a prediction of sustainability.

Elements of a good indicator:

- System oriented
- Quantitative
- Predictive
- Stochastic
- Diagnostic (Hansen, 1996)
- Readily measurable (Rigby, 2001)

Productivity as an Indicator of Sustainability

- A farm or agroecosystem is first and foremost a system of production.
- A system of production has the goal of converting inputs into desirable outputs.
- Any definition of agricultural sustainability must ultimately focus on the ability to produce.
- Three measurements of productivity:
  - Biological (biomass)
  - Economic (dollars)
  - Ecological Economic (true costs)

Impacts of concern -

Effects often considered in LCA

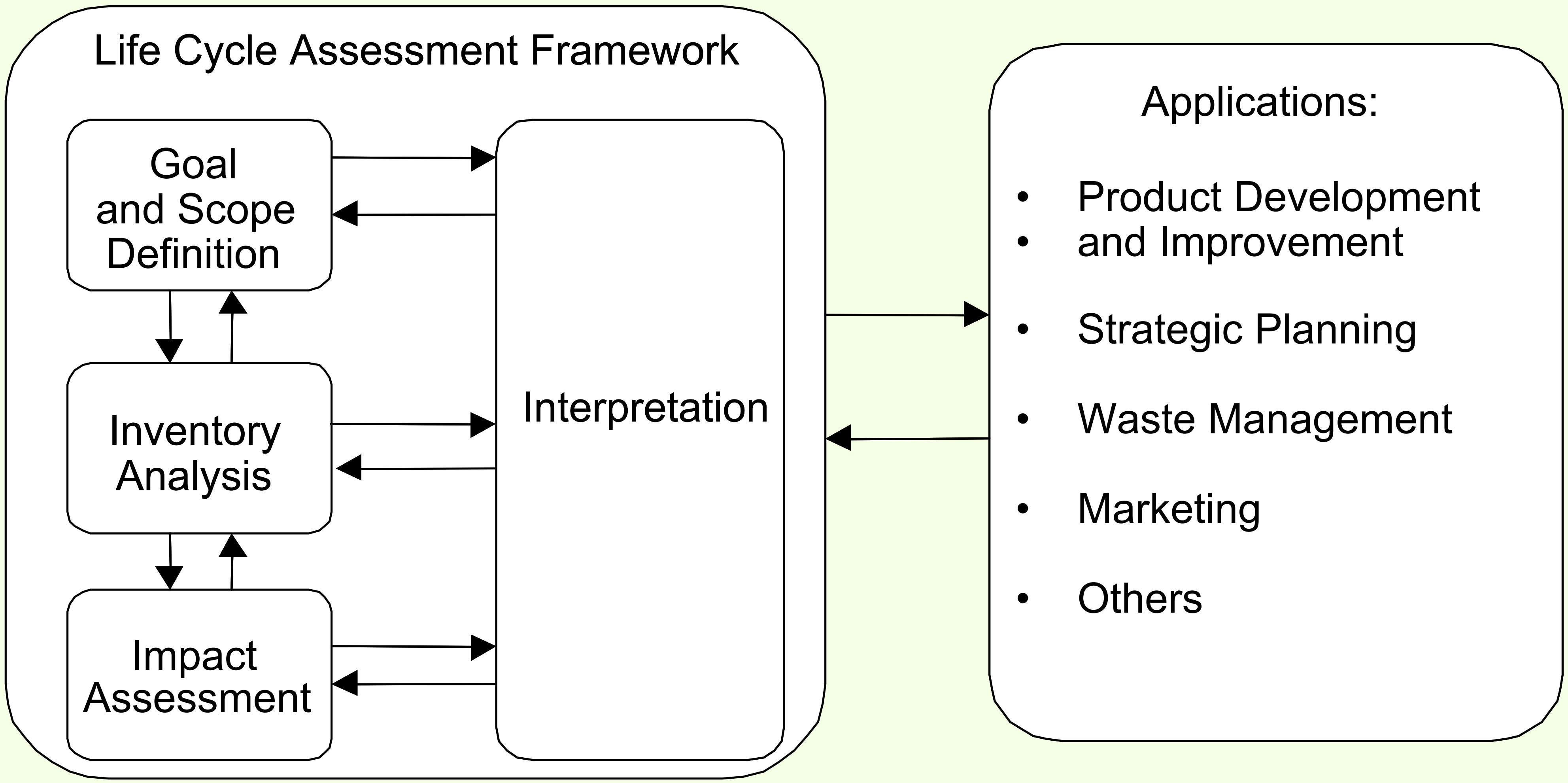
Group 1 Reasonable consensus exists	• Global warming (CO_2, CH_4, CFCs N_2O...)
	• Strat. ozone depletion (CFC, HCFC)
	• Eutrophication (N- and P- nutrients)
	• Acidification (Acid rain, NOx & SOx)
	• Ground level ozone (photooxidant formation)
	• Resource scarcity (Fossil fuel, rare metals...)
Group 2 Several different modeling approaches exist, if at all	• Biodiversity loss (Species extinction)
	• Ekotoxicity (Hg, PCB, ...)
	• Toxicity to humans (Hg, Pb, Cd, VCM...)
	• Water consumption
	• Land use

List of environmental effects (impact categories) treated in LCA

General distinction	Impact category
Input related categories	Depletion of abiotic resources
	Land use
Output related categories	Climate change (global warming)
	Stratospheric ozone depletion
	Human toxicity, ecotoxicity
	Photo-oxidant formation ('summer smog')
	Acidification
	Nutrification (eutrophication)

Life Cycle Assessment Phases

- based on ISO 14040



Life Cycle Assessment
Impact categories

Climate Change

- Caused by changes in the chemistry of the atmosphere, causing heat retention
- Primary problem is excess of CO_2, Methane and Nitrous Oxide, also some industrial chemicals
- Agriculture increases greenhouse gases by converting soil carbon into CO_2, and by high releases of Methane and Nitrous Oxide from ruminants and from anaerobic treatment of manure, and by burning fossil fuel

Global Warming Potential (GWP)

Different gases have different Global Warming Potential (GWP): The potency of a greenhouse gas is referred to as its global warming potential. The common unit is referred to as a carbon dioxide equivalent or CO_2 eq.

carbon dioxide (CO_2) =	1 CO_2 eq
methane (CH_4) =	23 CO_2 eq
nitrous oxide (N_2O) =	310 CO_2 eq

To convert tons of methane to CO_2 eq, simply multiply by 23.

Stratospheric Ozone Depletion

- The “hole” in the ozone layer
- Caused by release of freons and other industrial chemicals and some pesticides such as methyl bromine
- Management of refrigeration and pesticides needed to reduce this effect

Acidification

- "Acid Rain" comes from all burning, including internal combustion engines and diesel engines. It also can come from ammonia releases from manure lagoons
- Affects areas downwind if they have soils poor in lime and other neutralizing minerals: kills trees and water bodies
- Effects usually within 1000 miles downwind
- It is measured as kg SO_2-equivalent.
  - Sulphur dioxide (SO_2) = 1 SO_2-equivalent
  - Nitrogen oxides (NO_x) = 0.7 SO_2-equivalent
  - Ammonia (NH_3) = 1.88 SO_2-equivalents

Eutrophication

- Over-growth of algae in water, e.g. pond scum.
- Changes aquatic ecosystems and kills fish, a threat to biodiversity
- Caused by nutrients released into the land and air– effects can be thousands of miles away or local.
- Manure lagoons and burning of fossil fuels are primary sources
- It is measured as kg PO_4-equivalent.
- Phosphate (PO_4) = 1 PO_4-equivalent
- Nitrates to water (NO_3) = 0.1 PO_4-equivalent
- Ammonia (NH_3) = 0.33 PO_4-equivalents

Photochemical Smog

- Ozone and other nasty chemicals in the air we breathe
- Caused by oxides of nitrogen and volatile organic matter in sunlight
- Burning fossil fuels primary agricultural source
- Effects local or within a few hundred miles downwind

Air Toxics and Water Toxics

- Injures people, animals and plants through direct toxic effects
- Primary agricultural sources are nitrates from manure and over-fertilization, pesticides and the effects of burning fossil fuels
- Measured by looking at toxic strength and persistence

Resource Depletion

- Water
- Fossil Fuels
- Minerals (e.g. phosphate minerals)
- Water is renewable, but fossil fuels and minerals are not
- Depletion is the rate of excess use over reserves

Soil Conservation

- Basis of sustainable agriculture
- Controlled by tillage practices, e.g.
  - Contour plowing
  - No-till or low-till methods
  - Increasing organic matter in the soils through incorporating crop residues or other methods
- Rainfall also an important determinant

Land Use/Biodiversity

- Probably biggest impact of agriculture
- Direct replacement of natural ecosystems with crops
- Degree of impact based on fragmentation, and impacts on land/water interface
- Some ecologies especially fragile/rare/ important

Antibiotic Resistance

- Human antibiotics used in animals creates a large genetic pool of resistance
- Bacteria exchange genetic resistance across species
- Resistance passes to human pathogens, making antibiotics useless
- Problem has already killed people

Biohazard

- Transfer of disease from animal to animal and animal to human, like antibiotic resistance
- Can be caused by using meat byproducts in feed
- Inadequate sanitary measures also a potential problem
- Crowding is important issue

Hormone Use

- Hormone use has negative effect on health of animals
- Quality of meat may be affected (though the jury is still out on this)
- Fears of hormone residues in meat leading to human health issues
- Clear market signals to avoid use of hormones

Agricultural Activities

- Tillage
- Planting
- Fertilizing
- Pest Control
- Irrigation
- Cultivation
- Harvesting
- Feeding
- Veterinarian
- Manure Management
- Processing & Maintenance
- Transport

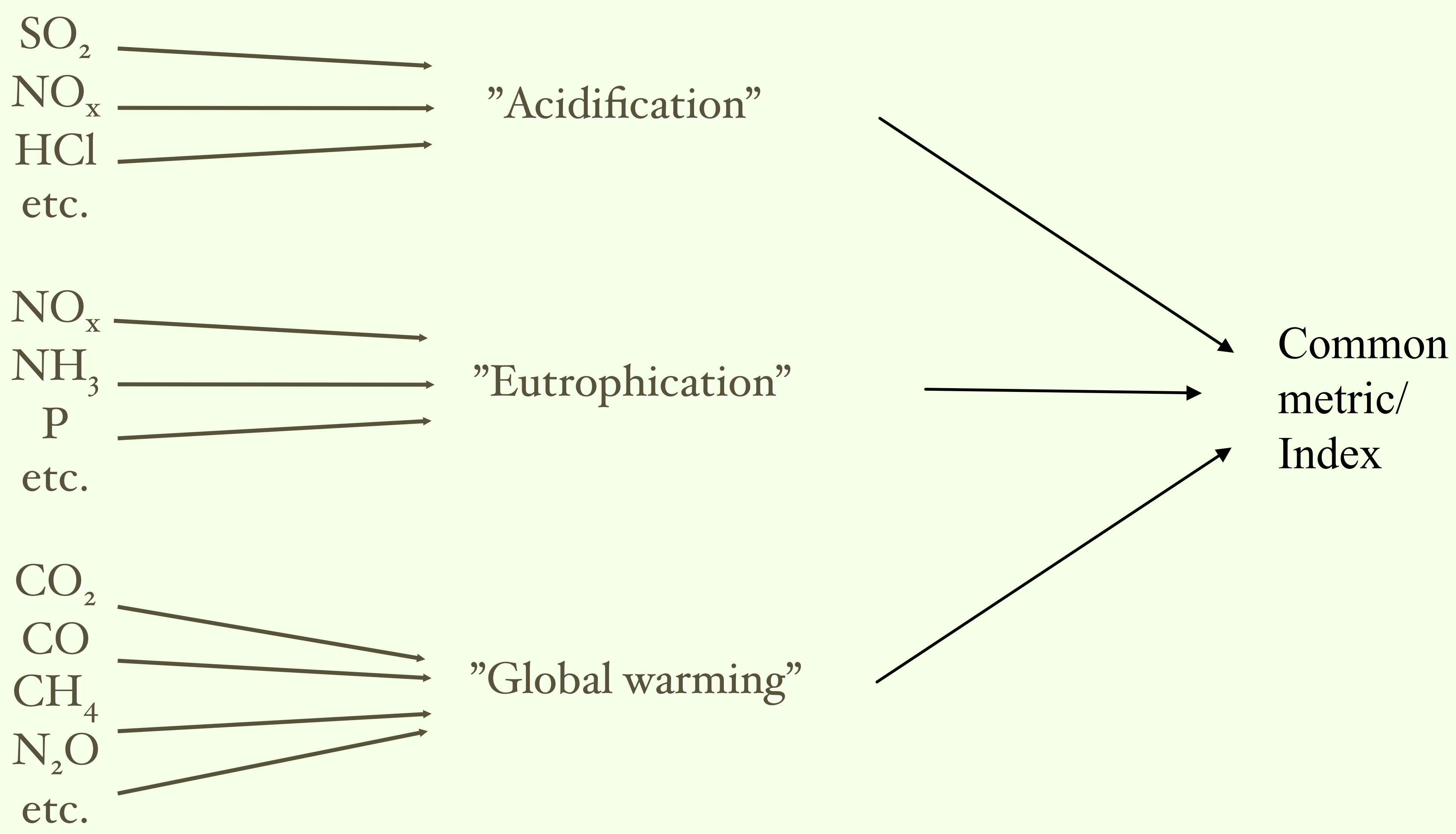
On-Farm Environmental Aspects

- Burning fossil fuels
- Physically changing soil structure
- Removing/restoring native habitat
- Use of N,P,S,K
- Use of Pesticides
- Use of water
- Use of electricity
- Use of GMO's
- Use of antibiotics
- Releases from lagoon or manure pile
- Use of freons
- Use of toxic chemicals
- Use of purchased feeds
- Use of meat by-products

LC Impact assessment

Inventory parameters | ***"Midpoint effects"*** | ***"Endpoint effects"/ Final result(s)***

Classification / characterisation | **Normalisation/weighting**



Approaches to weighting

- Expert panels
  - Consensus process / voting etc.
  - For the given study / given circumstances

- Relating to environmental standards
  - National political targets
  - Ecological targets / Acceptable damage levels

- Monetisation
  - Costs to society for damages caused
  - Willingness to pay / Costs to society for avoiding damages

Assessing the ecological soundness of organic and conventional agriculture by means of life cycle assessment (LCA): A case study of leek production

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Impact categories

Impact category	Unit	Contributing elements	Characterisation factor	Characterisation model description	Reference
Abiotic resource depletion	kg antimony equivalents (kg Sb- equivalents)			Abiotic depletion = $\sum_i ADP_i \times m_i$ ADP_i is the abiotic depletion potential of resource i, while m_i is the quantity of resource i used	Guinée and Heijungs, 1995
Climate change	kg CO_2-equivalents	CO_2 CH_4 N_2O	1 21 310	Climate change = $\sum_i GWP_{100,i} \times m_i$ $GWP_{100,i}$ is the global warming potential for substance i integrated over 100 years, while m_i is the quantity of substance i emitted	Houghton *et al.*, 1994, 1996
Stratospheric ozone depletion	kg trichlorofluoromethane equivalents (kg CFC-11 equation)	Methyl bromide Tetrachloromethane (CFC-10) CFC-11	0.37 1.2 1	Ozone depletion = $\sum_i ODP_{\infty,i} \times m_i$ $ODP_{\infty,i}$ is the steady-state ozone depletion potential for substance i, while m_i is the quantity of substance i emitted	WMO, 1992, 1999
Human toxicity	kg 1.4-dichlorobenzene equivalent (kg 1,4-DCB equation)	Heavy metals pesticides		Human toxicity = $\sum_i \sum_{ecom} HTP_{ecom} \times m_{ecom,i}$ $HTP_{ecom,i}$ is the human toxicity potential for substance i emitted to emission compartment ecom (= air, fresh water, seawater, agricultural or industrial soil), while $m_{ecom,i}$ is the emission of substance i to medium ecom (calculated with USES-LCA)	Huijbregts *et al.*, 2000; Huijbregts *et al.*, 2000

Impact categories

Impact category	Unit	Contributing elements	Characterisation factor	Characterisation model description	Reference
Terrestrial ecotoxicity	kg 1.4-dichlorobenzene equivalent (kg 1,4-DCB equation)	Heavy metals pesticides		Terrestrial ecotoxicity = $\sum_i \sum_{ecom} TETP_{ecom} \times m_{ecom,i}$ $TETP_{ecom,i}$ is the terrestrial ecotoxicity potential for substance i emitted emission compartment ecom, while $m_{ecom,i}$ is the emission of substance i to medium ecom (calculated with USES-LCA)	Huijbregts *et al.*, 2000; Huijbregts *et al.*, 2000
Photochemical oxidant formation	kg ethylene equivalents (kg C_2H_2-equation)	CH_4 aldehydes	0.007 0.443	Oxidant formation = $\sum_i POCP_i \times m_i$ $PCOP_i$ is the photochemical ozone creation potential for substance i, while m_i is the quantity of substance i emitted	Andersson-Sköld *et al.*, 1992
Acidification	kg SO_2-equivalents	NH_3 NO_x SO_2	1.6 0.5 1.2	Acidification = $\sum_i AP_i \times m_i$ AP_i is the acidification potential for substance i emitted to air, while m_i is the emission of substance i to the air	Huijbregts, 1999
Eutrophication	kg PO_4^{3-} equivalents	NH_3 NH_4^+ NO_3^- NO_x PO_4^{3-} P_2O_5	0.35 0.33 0.1 0.13 1 1.34	Eutrophication = $\sum_i EP_i \times m_i$ EP_i is the eutrophication potential for substance i emitted to air, water or soil while m_i is the emission of substance i to the air, water or soil	Heijungs *et al.*, 1992

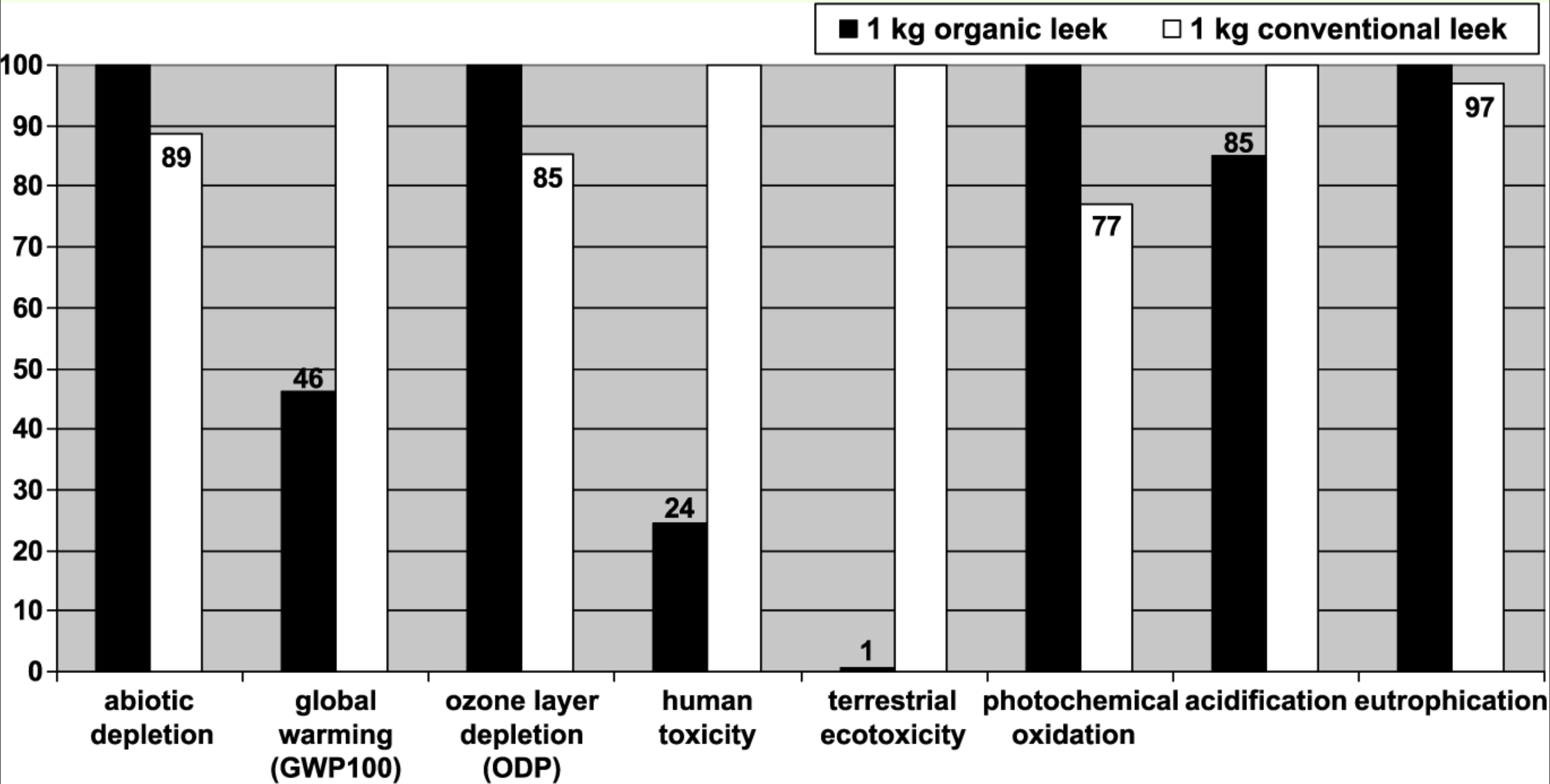
Operation	Diesel use (L/ha)[a]	Conventional Number of operations	Conventional Total (L/ha)	Organic Number of operations	Organic Total (L/ha)
Working green manure into soil (rotary cultivator)	7.5	1	7.5	1	7.5
Soil cultivation	4.6	1	4.6	1	4.6
Fertilisation – organic					
Loading	3.1	1	3.1	1	3.1
Spreading	11.6	1	11.6	1	11.6
Fertilisation – anorganic					
Loading	0.1	2	0.2	1	0.1[b]
Spreading	0.8	2	1.6	1	0.8[b]
Working manure into the soil	7.1	1	7.1	1	7.1
Applying lime	1.8	1	1.8	1	1.8
Ploughing	16.4	1	16.4	1	16.4
Rotary harrowing	7.7	1	7.7	1	7.7
Planting	17.8	1	17.8	1	17.8
Weeding and earthing up	3.1	2	6.2	5	15.5
Spraying	1.5	11	16.5	–	–
Harvesting	40	1	40	1	40
Total			142.1		134.0

Notes: [a]All data are from KTBL-report (2005) for average farms with parcels with average size of 2ha on sand loam soil; [b]spreading these organic fertilisers (e.g. blood meal) consumes an equal amount of diesel as the mineral fertiliser

Source: KTBL (2005)

Nitrogen balance	Conventional farming	Organic farming
N inputs (total)	373.88	258.88
Organic fertilizer application (kg N/ha)	125	235
Initial: cattle manure (kg N/ha)	*125*	*150*
Additional: dried blood and horn meal (kg N/ha)	–	*85*
Mineral fertilizer application (kg N/ha)	225	–
Biological fixation	–	–
Atmospheric N deposition (kg N/ha)	23.88	23.88
N outputs (total)	177.83	117.22
N removal with harvested crops (kg N/ha)	135	98.34
NH_3-N emissions (kg NH_4-N/ha)	7.75	3.90
due to organic fertilizer application (kg NH_4-N/ha)	*3.25*	*3.90*
due to mineral fertilizer application (kg NH_4-N/ha)	*4.5*	–
N_2O-N emissions (kg N_2O-N/ha)	4.28	1.83
N_2-N emissions (kg N_2-N/ha)	30.80	13.15
N balance = Σ input – Σoutput (kg NO_3-N/ha/year)	196.05	141.66

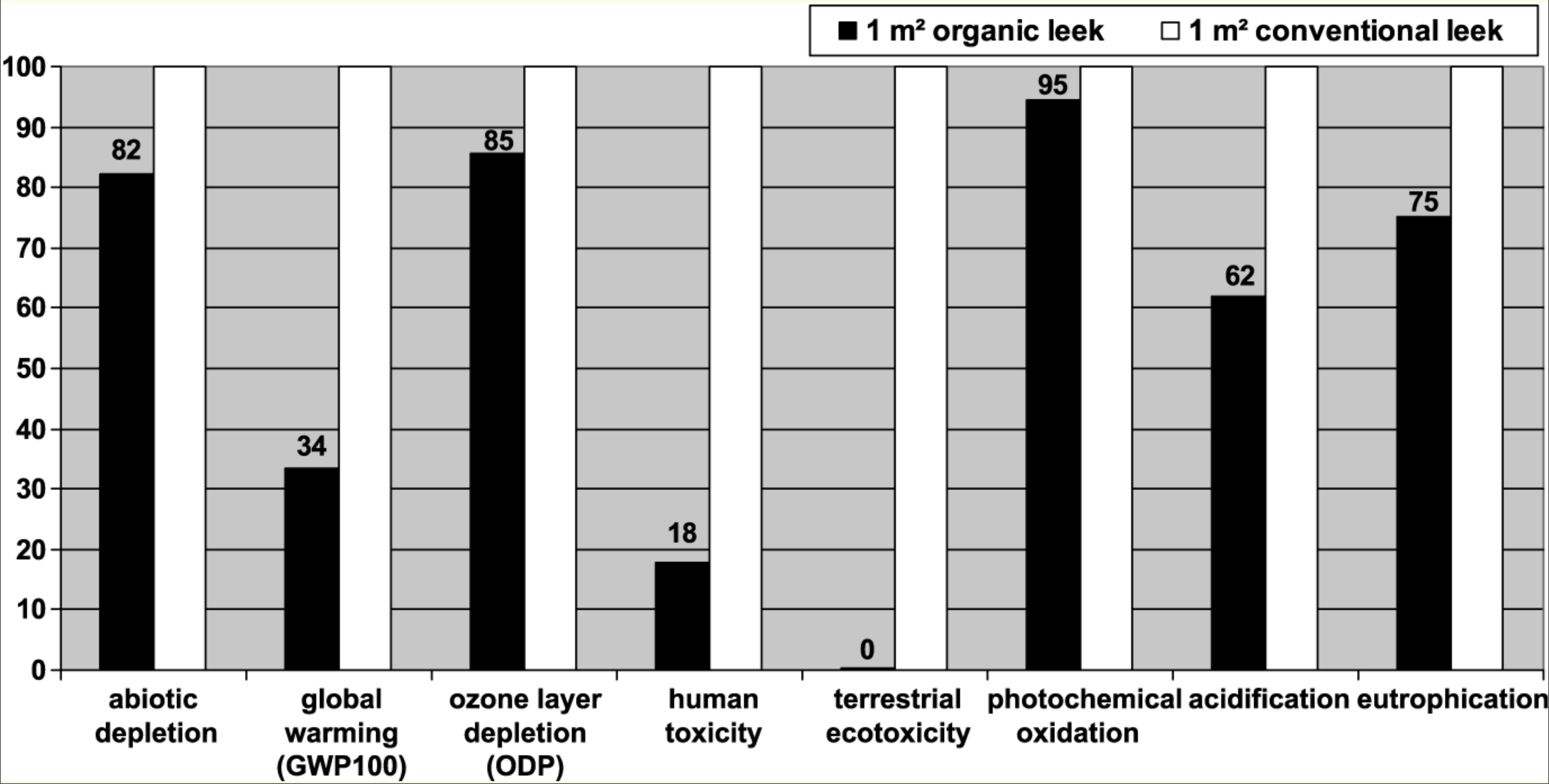
Comparison of the impact of 1 kg of organic and conventional leek production



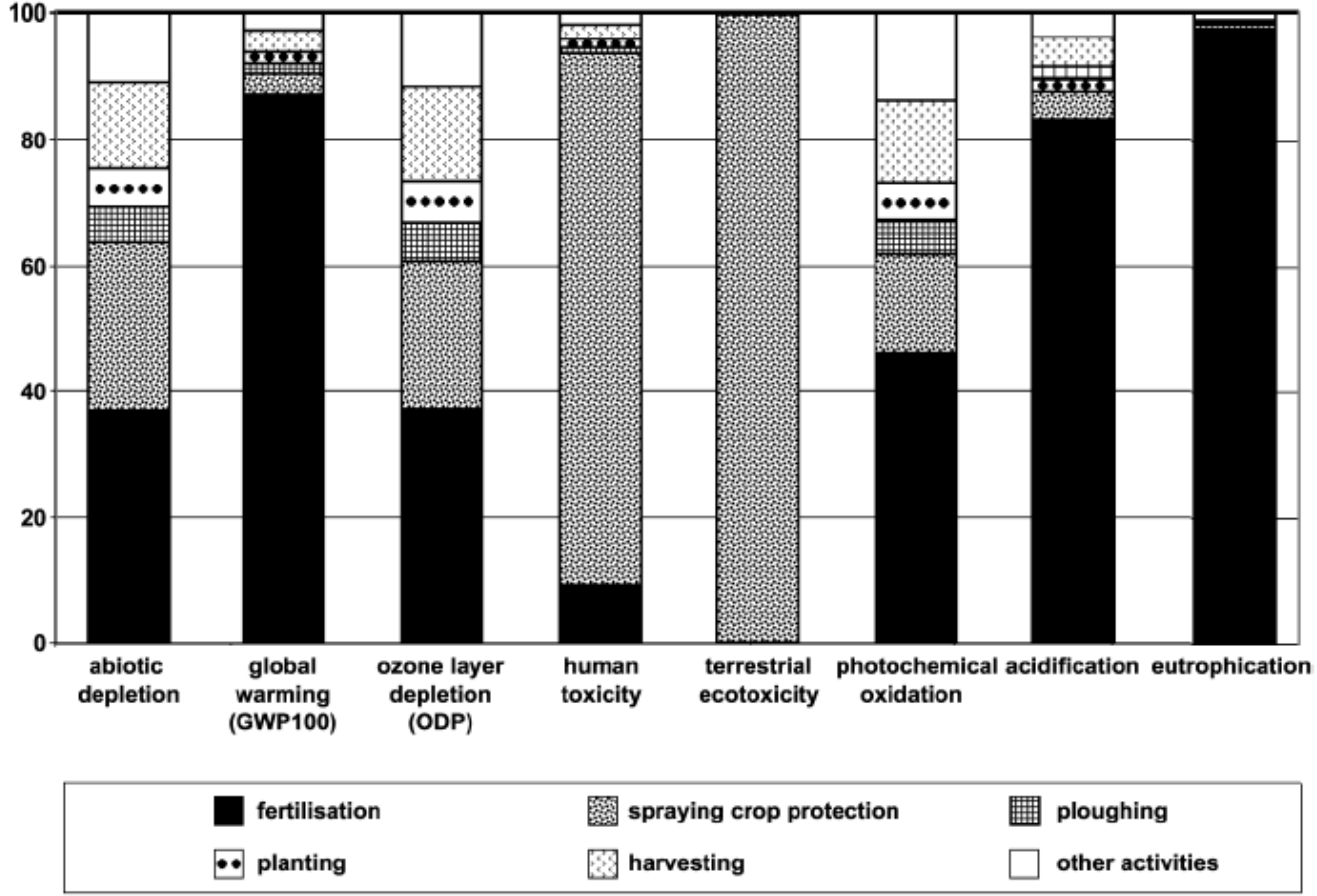
Comparison of the impact of 1 kg of organic and conventional leek production

Impact category	Impact indicator score Organic leek production	%	Conventional leek production	%
Abiotic resource depletion (kg Sb-equation)	1.75E-4	100	1.55E-4	89.09
Climate change (kg CO_2-equation)	4.35E-2	46.08	9.44E-2	100
Stratospheric ozone depletion (kg CFC-equation)	3.59E-8	100	3.06E-8	85.24
Human toxicity (kg 1.4-DB-equation)	7.48E-3	24.36	3.07E-2	100
Terrestrial ecotoxicity (kg 1.4-DB-equation)	3.53E-5	0.51	6.91E-3	100
Photochemical oxidant formation (kg C_2H_4-equation)	7.34E-6	100	5.66E-6	77.11
Acidification (kg SO_2-equation)	3.82E-4	84.89	4.50E-4	100
Eutrophication (kg PO_4-equation)	6.94E-4	100	6.74E-4	97.12

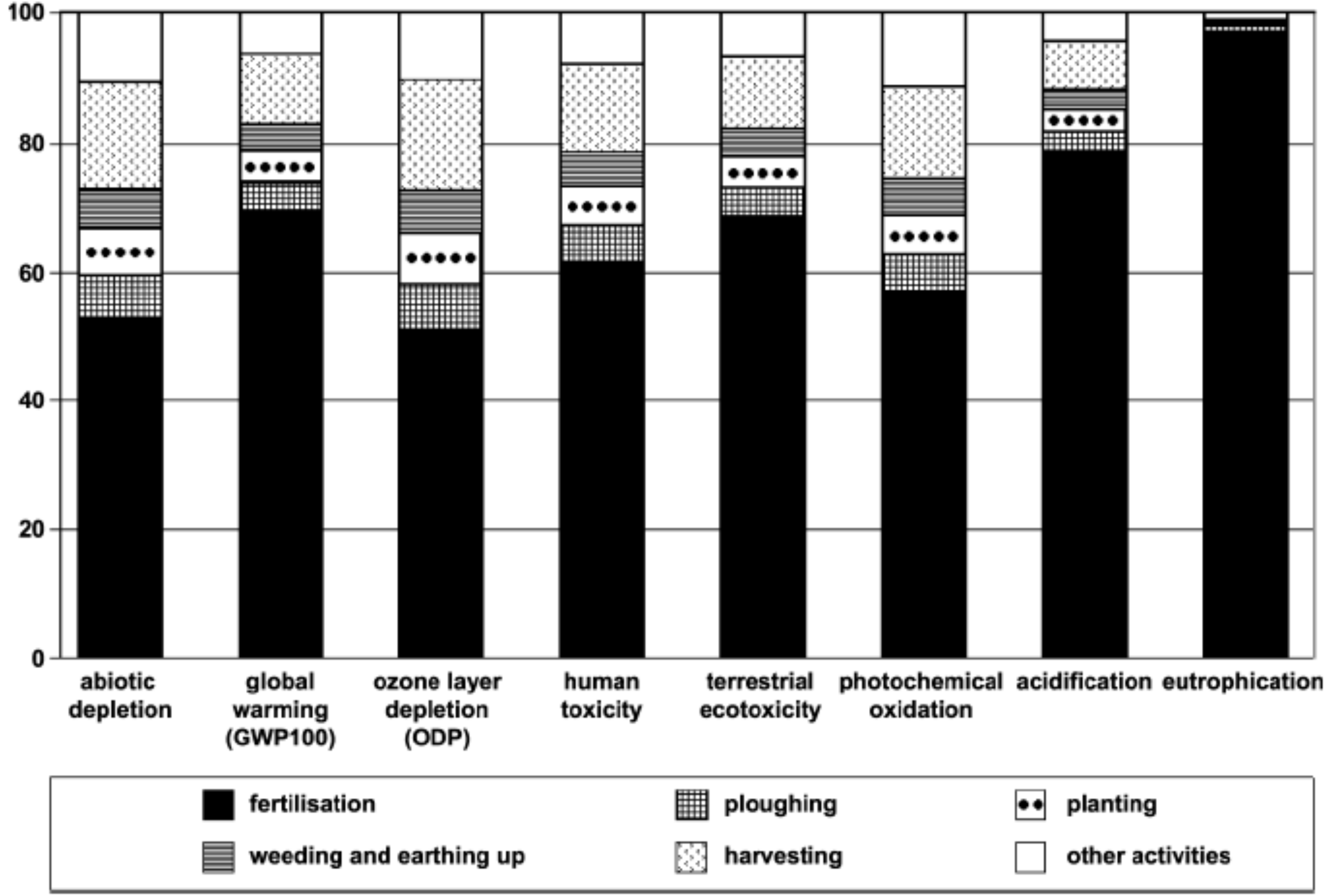
Comparison of the impact of 1 m² of organic and conventional leek production



Impact category	Impact indicator score Organic leek production	%	Conventional leek production	%
Abiotic resource depletion (kg Sb-equation)	4.81E-4	82.22	5.85E-4	100
Climate change (kg CO_2-equation)	1.20E-1	33.61	3.57E-1	100
Stratospheric ozone depletion (kg CFC-equation)	9.88E-8	85.17	1.16E-7	100
Human toxicity (kg 1.4-DB-equation)	2.06E-2	17.76	1.16E-1	100
Terrestrial ecotoxicity (kg 1.4-DB-equation)	9.71E-5	0.37	2.60E-2	100
Photochemical oxidant formation (kg C_2H_4-equation)	2.02E-5	94.84	2.13E-5	100
Acidification (kg SO_2-equation)	1.05E-3	61.76	1.70E-3	100
Eutrophication (kg PO_4-equation)	1.91E-3	75.20	2.54E-3	100



Contribution of farming activities (in %) to the environmental impact indicators, for the production of conventional leek



Contribution of farming activities (in %) to the environmental impact indicators, for the production of organic leek

The choice of the functional unit

- The impact assessment is largely dependent on the choice of the FU, which should be related to the main functions assigned to the farming system and the objectives of the evaluation
- When the FU is per kg production both the production efficiency and the environmental impact are considered.
- When the focus is on the environmental impact in a local area, the FU per area production, is more appropriate.
- The influence of the choice of FU is very important when comparing systems with different levels of productivity per ha, such as conventional and organic farming

- This study shows that when assessed on area basis organic farming shows a more favourable environmental profile.
- Suggested improvements for conventional farming are improving the farm nutrient flows in order to reduce nutrient surplus, optimizing the energy and fuel use, increasing its self-supporting capacity and reducing the use of toxic pesticides.
- Since the yields obtained by organic farming are lower compared with conventional farming, the overall environmental benefits are strongly reduced or even disappear after correcting for these lower produced quantities per hectare. Therefore, more research should be done on how the yields in organic farming can be substantially increased without increasing the environmental burden.
- This LCA study only highlights the ecological aspect of sustainability. To get an overall picture of the sustainability of organic and conventional farming, social and economical aspects should also be taken into consideration.

Comparing intensive, extensified and organic grassland farming in southern Germany by process life cycle assessment

G. Haas et al. / Agriculture, Ecosystems and Environment 83 (2001) 43–53

Data for analyzed dairy farms of life cycle assessment in the Allgäu region[a]

	Farming intensity		
	Intensive	Extensified	Organic
Characteristics			
Mineral N-fertilizing	Yes	No	No
Purchasing fodder	Yes	Yes	Limited
Share of farms in the region	43%	46%	6%
Farming intensity period (years)	–	5 (2–7)	13 (3–20)
Farmed grassland area (ha)	32.7 (23–46)	34.7 (17–62)	25.8 (16–34)
Grassland yield (gross — without harvest losses) (t DM ha^{-1})	11.8 (10.9–12.8)	10.5 (90–12.7)	10.7 (88–12.1)
Stocking rate (LU ha^{-1})[b]	2.2 (2.0–2.6)	1.9 (1.6–2.3)	1.9 (1.6–2.1)
Milk performance (annual) (kg per cow)	6758 a (5100–8050)	6390 ab (5500–7640)	5275 b (4800–5500)

[a] Mean of farming system, range in brackets. Values followed by letters indicate mean significant difference (MSD) of 1148.5 kg per cow; other parameters are not significant.

[b] LU: livestock-unit (each 500 kg liveweight).

Impact categories and indicators of life cycle assessment in the Allgäu region

Impact category	Environmental indicator
Resource consumption	
Energy	Use of primary energy
Minerals	Use of P- and K-fertilizer
Global warming potential	CO_2-, CH_4-, N_2O-emission (in CO_2-equivalents)
Soil function/strain	
Grassland	Accumulation of heavy metals
Of other ecosystems (acidification, eutrophication)	NH_3-, NO_x-, SO_2-emission, N- and P-surplus (in SO_2- and PO_4-equivalents)
Water quality	
Ground water (nitrate content)	N-fertilizing, N-farmgate-balance, potential of nitrate leaching
Surface water (P-eutrophication)	P-fertilizing, P-balance, percentage of drained area
Human- and ecotoxicity	Application of herbicide and antibiotics, potential of nitrate leaching, NH_3-emission
Biodiversity	Grassland (number of species, date of first cut), hedges and field margins (density, diversity, state/care, fences)
Landscape image (aesthetics)	Grassland, hedges and field margins (see above), grazing animals (period, breed, alpine cattle keeping), layout of farmstead (regional type, buildings, farm garden, trees, orchard)
Animal husbandry (appropriate animal welfare)	Housing system and conditions, herd management (e.g. lightness, spacing, grazing season, care)

Biodiversity Indicators

Estimation of the impact category biodiversity of life cycle assessment in the Allgäu region[a]

	Index				
	5	4	3	2	1
Grassland					
Number of species (flora)	≤22	23–25	26–28	29–31	≥32
Time of first cut (after)	5 May	10 May	15 May	20 May	25 May
Hedges and field margins					
Density (relative frequency)	Low		Average		High
Diversity	Low		Average		High
State/care	Poor		Average		Very good
Fences	None		Medium density, small fences		High density, broad fences

[a] 1: very good; 3: average of region; 5: unsatisfactory.

Table 1: Impact categories and indicators of the Allgäu LCA

Impact category	Environmental indicator
Resource consumption energy minerals	 Use of primary energy Use of P- & K-fertiliser
Global warming potential	CO_2, CH_4, N_2O-emission
Soil function/strain grassland of other ecosystems (N-eutrophication, acidification)	 Accumulation of heavy metals NH_3, NO_x, SO_2-emission
Water quality ground water (nitrate leaching) surface water (P-eutrophication)	 N-fertilising, N-farmgate-balance, potential of nitrate leaching, P-fertilising, P-balance, % of drained area
Human and ecotoxicity	Application of herbicides and antibiotics, potential of nitrate leaching, NH_3-emission
Biodiversity	Grassland (number of species, date of first cut), hedges & field margins (density, diversity, state, care)
Landscape image (aesthetics)	Grassland, hedges & field margins (see above), grazing animals (period, breed, alpine cattle keeping), layout of farmstead (regional type, buildings, garden)
Animal husbandry (appropriate animal welfare)	Housing system & conditions, herd management (e.g. lightness, spacing, grazing season, care)

Table 3: Emission of CO_2-equivalents (mean, lower range) of different farming intensities depending on the functional unit chosen – impact category 'global warming potential' of the Allgäu LCA

Functional unit	Unit	Farming intensity		
		Intensive	Extensive	Organic
Farm	t	306 205-514	239 118-404	165 90-236
Area	t/ha	9.4 7.5-11.2	7.0 5.7-8.3	6.3 5.6-7.3
Livestock	t/LU*	138 88-223	129 59-252	86.5 53-113
Product (milk)	t/t	1.3 1.1-1.7	1.0 0.9-1.2	1.3 1.2-1.4

*LU livestock-unit (each 500 kg live-weight of cattle)

Inventory of the impact category primary energy consumption of life cycle assessment in the Allgäu region[a]

Impact category/indicator	Intensive	Extensified	Organic	$MSD_{5\%}$
Fuel and lubricants for grassland farming ($GJ\,ha^{-1}$)	4.482	4.117	3.439	n.s.
Hay drying (indoor) ($GJ\,ha^{-1}$)	0.721	0.320	0.966	n.s.
Grass drying (in industrial plants) ($GJ\,ha^{-1}$)	6.391 a	0.306 b	0.745 b	5.21
Mineral fertilizer ($GJ\,ha^{-1}$)	3.674 a	0.194 b	0 b	1.08
Purchased fodder ($GJ\,ha^{-1}$)	3.836 a	3.724 a	0.790 b	2.88
Energy consumption				
Primary energy (area-related) ($GJ\,ha^{-1}$)	19.1 a (10.4–28.7)	8.7 b (5.5–12.2)	5.9 b (3.8–10.6)	7.23
Primary energy (product-related: t milk) ($GJ\,t^{-1}$)	2.7 a (1.6–3.9)	1.3 b (1.0–1.6)	1.2 b (0.8–1.8)	0.98

[a] Mean and range (in brackets) of farming system. Differences between the means (MSD) were tested using the Tukey test at the alpha 5% level indicated by different letters or as not significant (n.s.).

Inventory of the impact category global warming potential of life cycle assessment in the Allgäu region[a,b]

Impact category/indicator	Intensive	Extensified	Organic	$MSD_{5\%}$
CO_2-emission	1.280 a	0.666 b	0.428 b	0.45
CH_4-emission	5.102 a	4.535 ab	4.114 b	0.77
N_2O-emission	3.017 a	1.808 b	1.776 b	0.65
Global warming potential				
Area-related ($t\,ha^{-1}$)	9.4 a (7.5–11.2)	7.0 b (5.7–8.0)	6.3 b (5.6–7.3)	1.66
Product-related ($t\,t^{-1}$ milk)	1.3 a (1.1–1.7)	1.0 b (0.9–1.2)	1.3 a (1.2–1.4)	0.22

[a] In t CO_2-equivalents; mean and range (in brackets) of farming system.
[b] Differences between the means (MSD) were tested using the Tukey test at the alpha 5% level indicated by different letters.

Inventory of the impact category eutrophication and acidification of life cycle assessment in the Allgäu region[a,b]

Impact category/indicator	Intensive	Extensified	Organic	$MSD_{5\%}$
Acidification (in SO_2-equivalents)				
SO_2-emission	1.1 a	0.7 b	0.3 c	0.31
NO_x-emission	6.1 a	4.6 a	2.6 b	1.94
NH_3-emission	129 a	113 ab	104 b	21.68
Sum[b]	136 a (119–145)	119 ab (96–143)	107 b (94–118)	23.01
Eutrophication (in PO_4-equivalents)				
No_x-emission	1.13 a	0.86 a	0.48 b	0.36
N (farmgate balance)[c]	33.6 a	13.4 b	13.1 b	15.0
P (farmgate balance)[c]	19.5	16.9	0	n.s.
Sum[b]	54.2 a (17.8–90.1)	31.2 ab (0.6–48.6)	13.5 b (7.4–19.0)	28.3

[a] In $kg\,ha^{-1}$; mean and range (in brackets) of farming system.

[b] Differences between the means (MSD) were tested using the Tukey test at the alpha 5% level indicated by different letters or as not significant (n.s.).

[c] Calculated eutrophication potential for N and P are based on the farmgate balances for these elements (see Tables 7 and 8), but only positive N and P farm-balances were considered.

Inventory of the impact category ground water quality (N-balance) of life cycle assessment in the Allgäu region[a]

	Indicator	Intensive	Extensified	Organic	$MSD_{5\%}$
A	N-fertilizer	68.1 (35.5–100.7)	0	0	
B	Purchased fodder, straw and cattle	39.5 ab (23.5–65.2)	45.0 a (9.2–85.6)	11.9 b (2.3–19.6)	28.74
C	Symbiotic N_2 fixation	20.3 b (9.0–28.0)	31.7 b (20.0–48.0)	50.2 a (28.0–62.0)	14.92
D	N-export	47.8 a (37.3–62.5)	45.3 a (39.0–56.8)	31.0 b (25.4–38.4)	11.07
T_1	N-farmgate balance[b]	80.1 a (40.4–115)	31.4 b (−3.8–66.2)	31.1 b (16.2–44.2)	36.21
E	Atmospheric deposition	20.0	20.0	20.0	–
F	Ammonia losses	55.9 (48.6–63.4)	49.6 (40.4–60.1)	45.4 (39.6–50.5)	n.c.
G	Denitrification	8.1 (6.9–9.1)	6.0 (4.8–7.4)	6.2 (5.0–7.0)	n.c.
T_2	Potential NO_3-N-leaching[c]	36.0 a (2.9–63.5)	4.3 b (−37.4–25.8)	−0.5 b (−9.2–6.8)	31.59
	Total N-fertilizing[d] (mineral fertilizer and slurry)	212.5 a (166–255)	128.0 b (104–157)	116.7 b (102–130)	36.21

[a] In kg N ha^{-1}; mean and range (in brackets) of farming system. Differences between the means (MSD) were tested using the Tukey test at the alpha 5% level indicated by different letters; not computed (n.c.) because calculations are based on rough figures.

[b] N-farmgate balance: $T_1=A+B+C-D$.

[c] Negative values for potential nitrate leaching are not very meaningful, but do show variation and differences between the systems ($T_2=T_1+E-F-G$).

[d] Values for the total amount of fertilizing only serve as an additional indicator that is not part of the farmgate balance.

Inventory of the impact category surface water quality (P-balance) of life cycle assessment in the Allgäu region[a]

	Indicator	Intensive	Extensified	Organic	$MSD_{5\%}$
A	Mineral P-fertilizer	5.4 (0–18.0)	4.6 (0–15.4)	0	
B	Purchased fodder, straw and cattle	8.2 ab (4.8–12.2)	8.4 a (1.9–14.2)	3.8 b (2.9–6.1)	4.41
C	P-export	8.3 a (7.1–9.9)	8.5 a (7.3–10.5)	6.1 b (5.0–7.6)	1.72
T_3	P-farmgate balance[b]	5.3 (−3.3–17.1)	4.5 (−5.4–12.7)	−2.3 (−4.6–0.5)	n.s.
	Total P-fertilizing[c] (mineral fertilizer and slurry)	34.6 a (27.0–48.6)	30.9 ab (23.5–40.7)	23.2 b (20.0–26.0)	8.90

[a] In kg P ha^{-1}; mean and range of farming system. Differences between the means (MSD) were tested using the Tukey test at the alpha 5% level indicated by different letters or as not significant (n.s.).

[b] P-farmgate balance: $T_3 = A + B - C$.

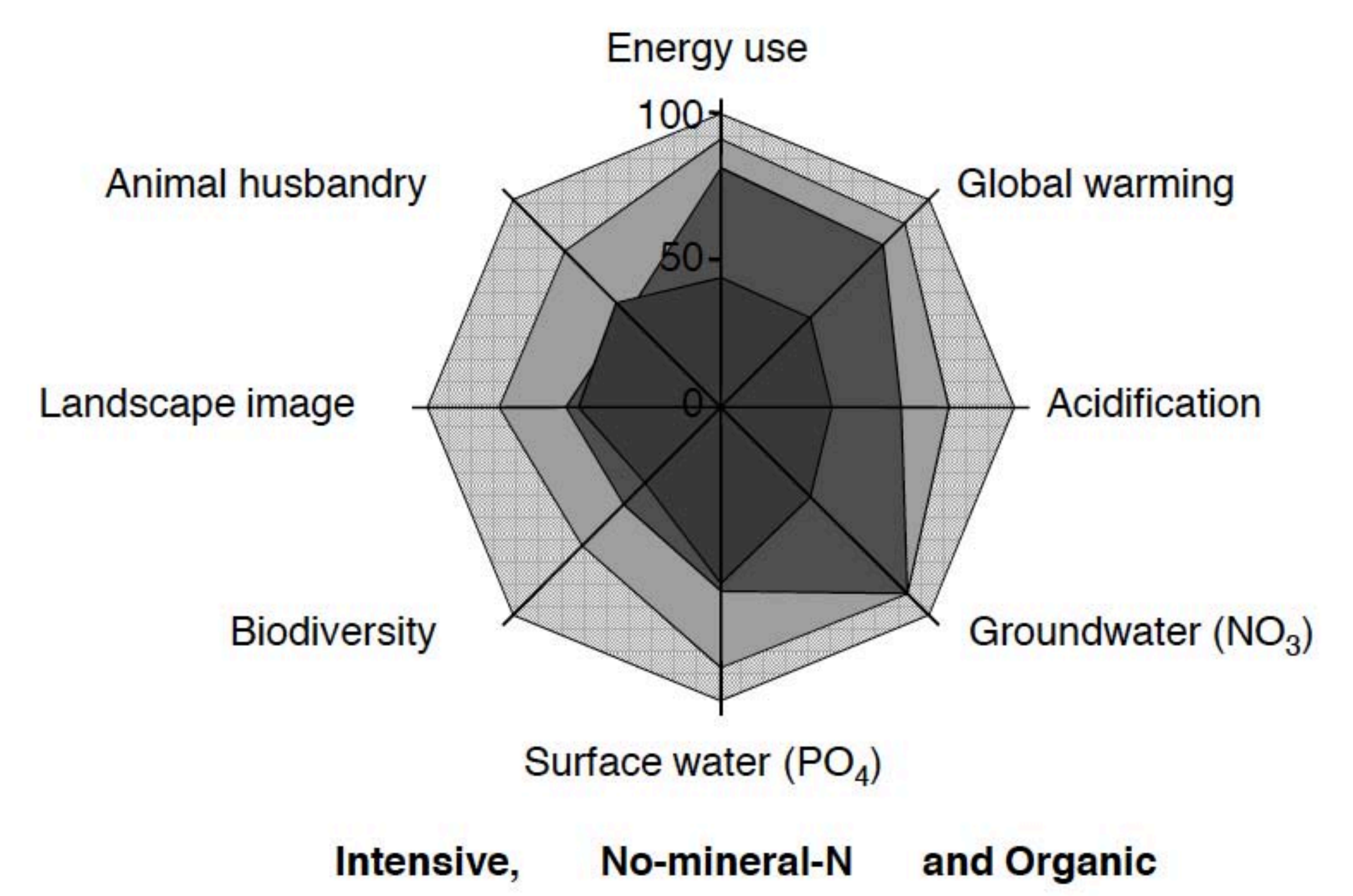
[c] Values for the total amount of fertilizing only serve as an additional indicator that is not part of the farmgate balance.

Inventory of the impact category biodiversity, landscape image and animal husbandry of life cycle assessment in the Allgäu region[a]

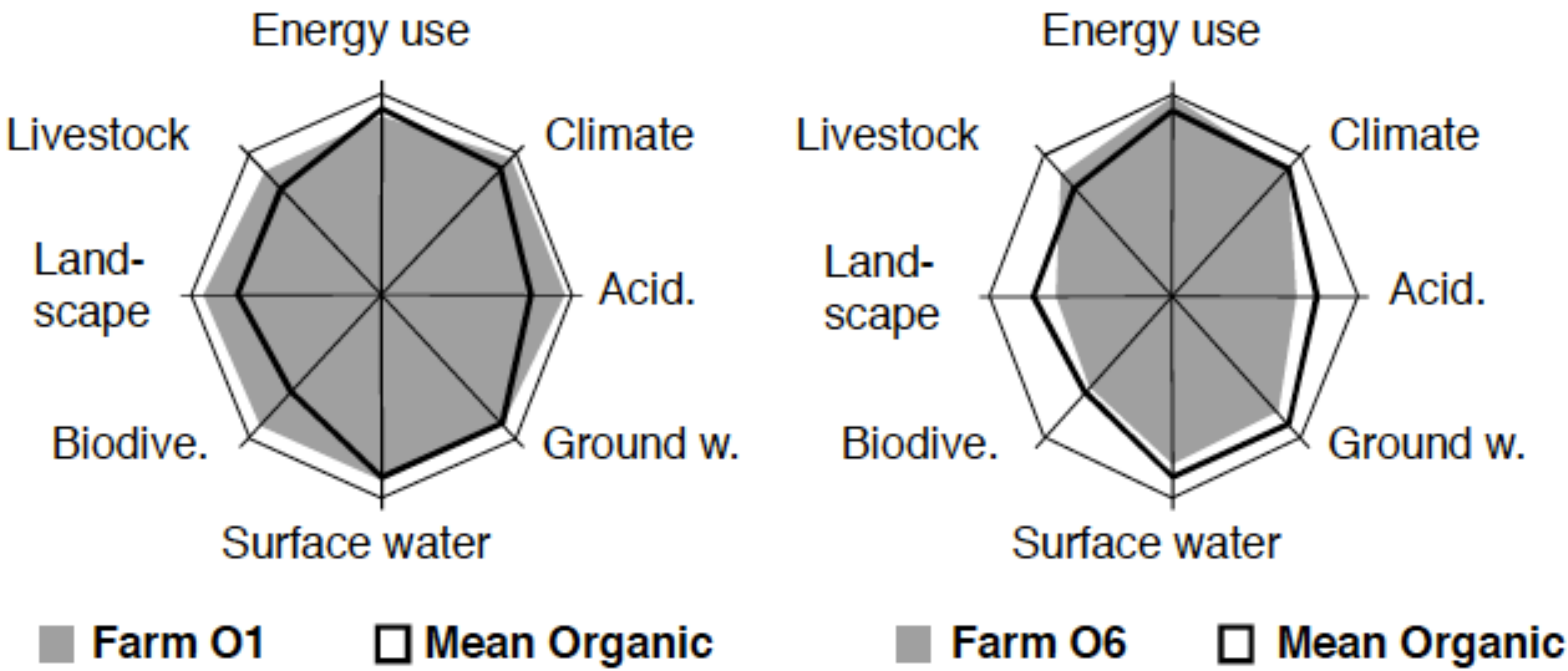
Impact category/indicator	Intensive	Extensified	Organic
Biodiversity	3.7	3.3	2.4
Grassland	3.6 (3.0–4.0)	3.5 (2.5–5.0)	2.1 (1.5–4.0)
Hedges and field margins	3.8 (1.5–4.8)	3.0 (1.3–4.0)	2.7 (1.3–3.8)
Landscape image (partly including biodiversity)	3.2	3.0	2.0
Grazing cattle	2.7 (1.8–3.5)	3.0 (1.3–5.0)	1.8 (1.0–2.5)
Farmstead	2.6 (1.0–3.8)	2.5 (1.8–3.3)	1.5 (1.0–2.5)
Animal husbandry	3.1	3.3	2.0
Housing system	3.2 (2.1–3.6)	3.3 (1.7–4.8)	2.5 (1.8–3.4)
Herd management	3.0 (2.0–4.0)	3.3 (1.8–4.5)	1.5 (1.0–2.3)

[a] Estimation index: 1: very good, 3: average of the region, 5: unsatisfactory; mean of farming system, range in brackets.

Comparing Environmental Impact of Farming System



Dairy-Grassland-Farms in the Allgäu Region (mean of 6 each)


Energy use
Climate
Acid.
Ground w.
Surface water
Biodive.
Land-
scape
Livestock
Farm O1
Mean Organic
Energy use
Climate
Acid.
Ground w.
Surface water
Biodive.
Land-
scape
Livestock
Farm O6
Mean Organic

First Life Cycle Assessment of milk production in New Zealand

NZ Agriculture and LCA

- Current situation:
  - A dynamic and autonomous sector compared to agriculture in Europe, focused on exportation
  - High level of requirement on the environmental performance of NZ farming systems (preserving NZ sensitive ecosystems and marketing advantage on the world market)
- Trends
  - Intensification of farming systems to increase milk production
- LCA
  - A tool for strategic decisions for both farmers, politics and researchers

Why Life Cycle Assessment?

- From the process-oriented approach to the product-oriented one...
  - Take the problem more globally
  - Over the whole life cycle of a product
  - global and regional impacts
- Life Cycle Assessment recommended by EU and UN
- LCA has been applied to a range of agricultural products during the last ten years (milk, pig, beef, fish, wheat, chicken, apple, wine....)

1st step: goal and scope of the study

- Produce a complete picture of the environmental performance of NZ milk production compared with European systems

- Average NZ scenario of milk production: national statistics

Technical description of the NZ milk production scenario

Dairy farm	*Data*	*Reference*
Area (ha)	111	LIC, 2003
Cows	285	LIC, 2003
Stocking rate (max cow/ha/year)	2.7	Dexcel,
Milk solids (kg/ha/year)	828	LIC, 2003
N fertilizer use (kg/ha/year)	110	Dexcel,
P fertilizer use (kg/ha/year)	51	Dexcel,
Pasture dry matter intake (kg	10189	OVERSEE
Maize silage and forage (kg DM/	931	Dexcel,

1st step: goal and scope of the study

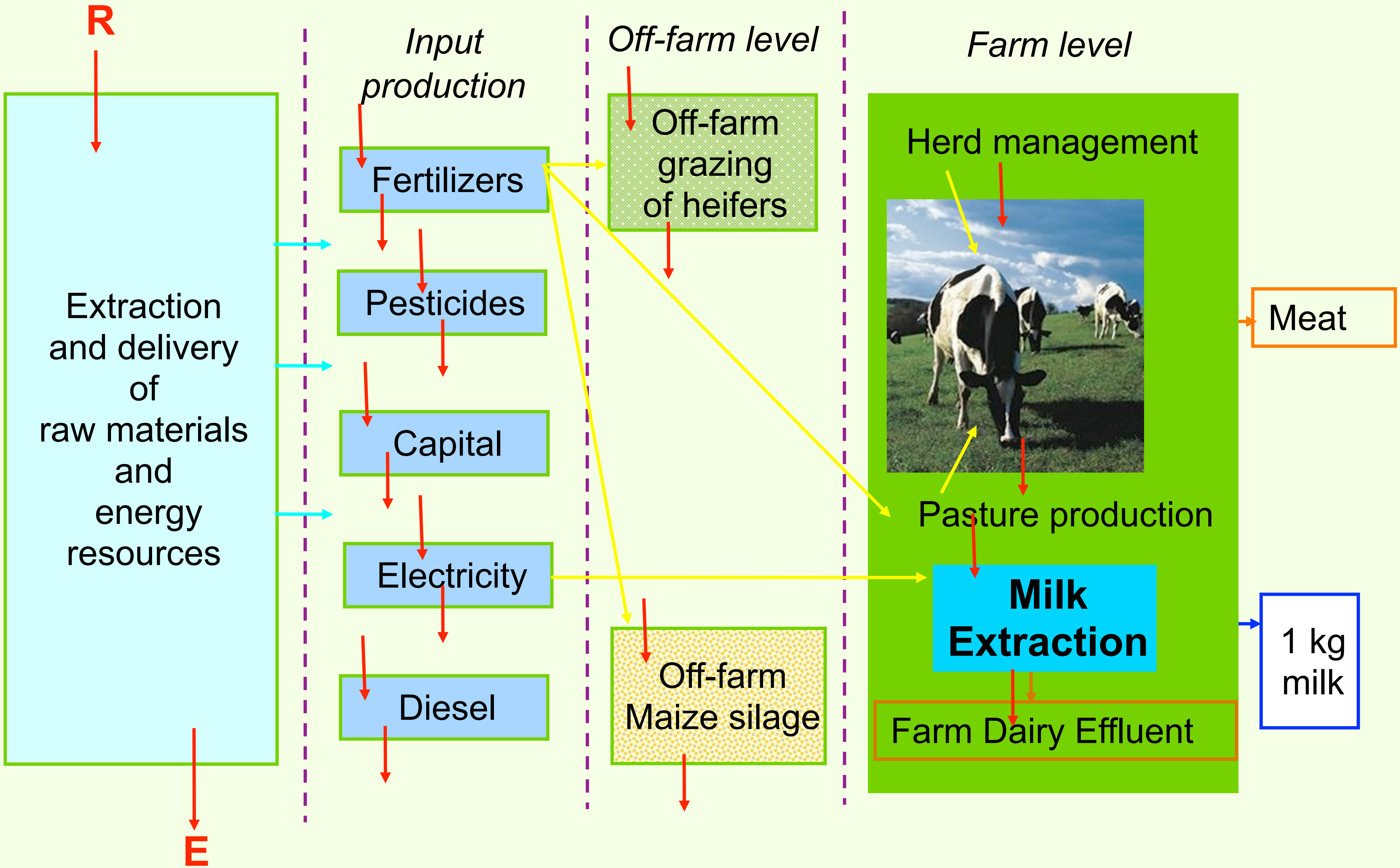
- Limits of the system: “from cradle to gate”

1st step: goal and scope of the study

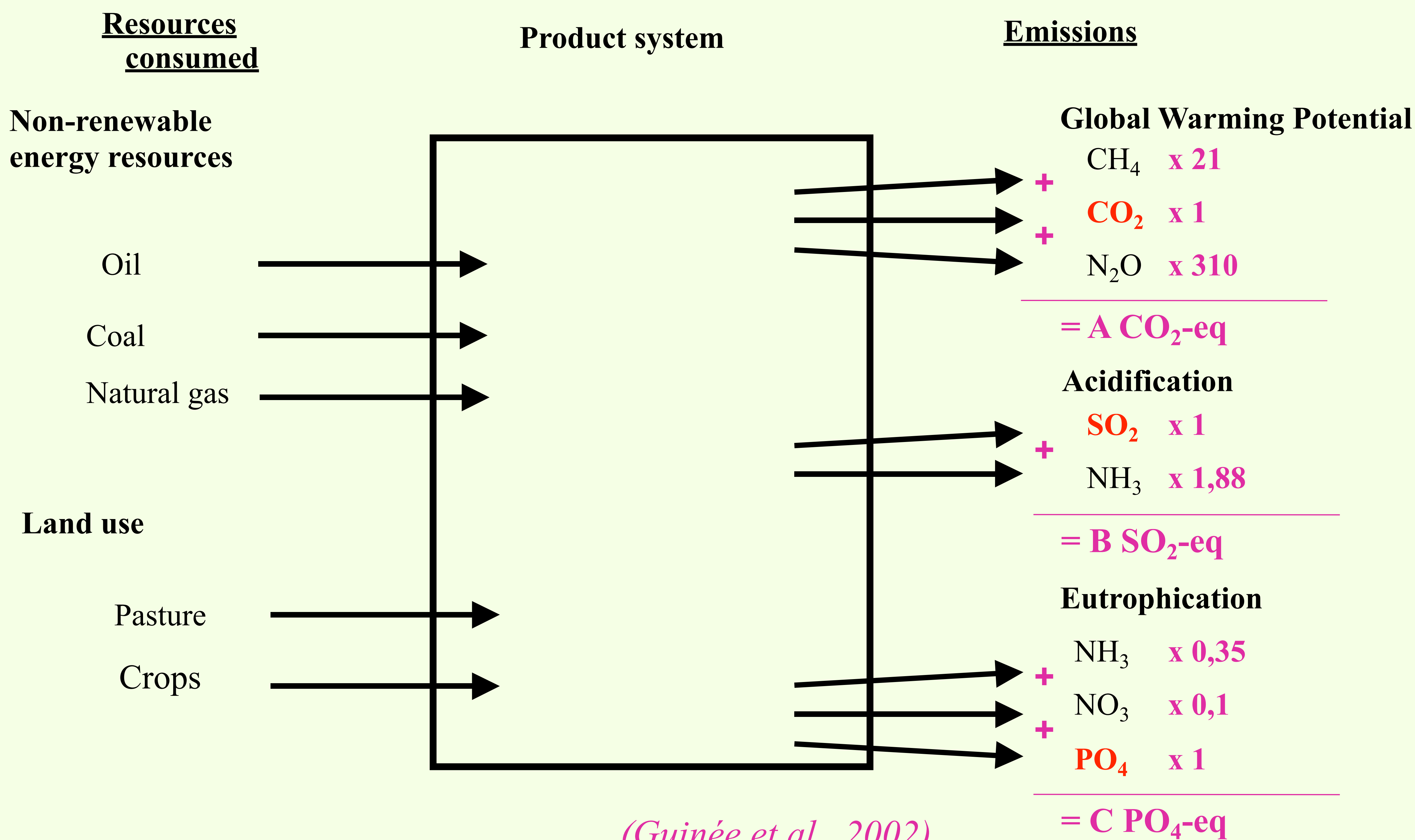
- Limits of the system: “from cradle to gate”

- Functional unit:
  - 1 kg of milk
  - 1 ha of surface used

2nd step: inventory analysis of resources used and emissions



3rd step: impact assessment

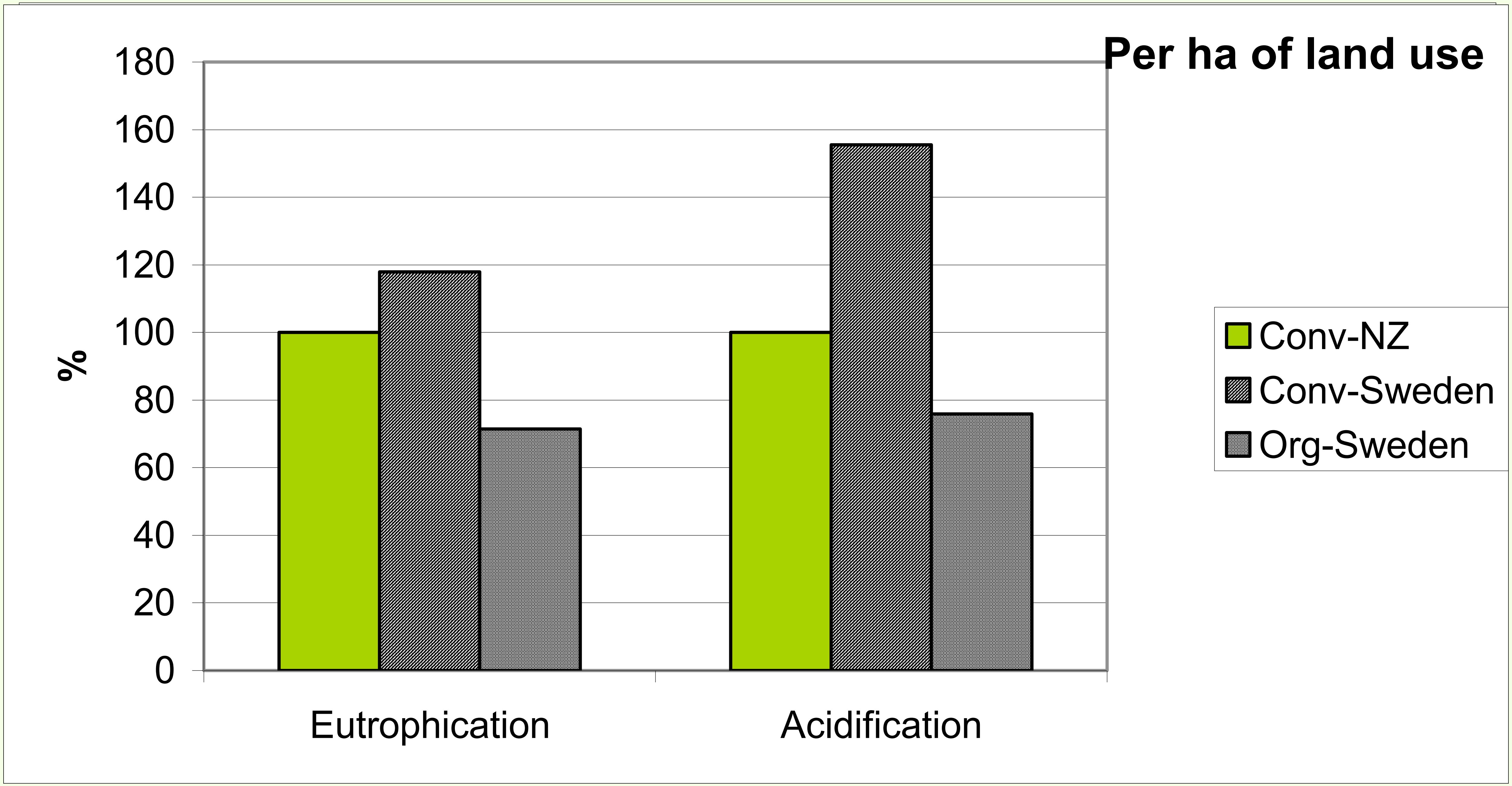


(Guinée et al., 2002)

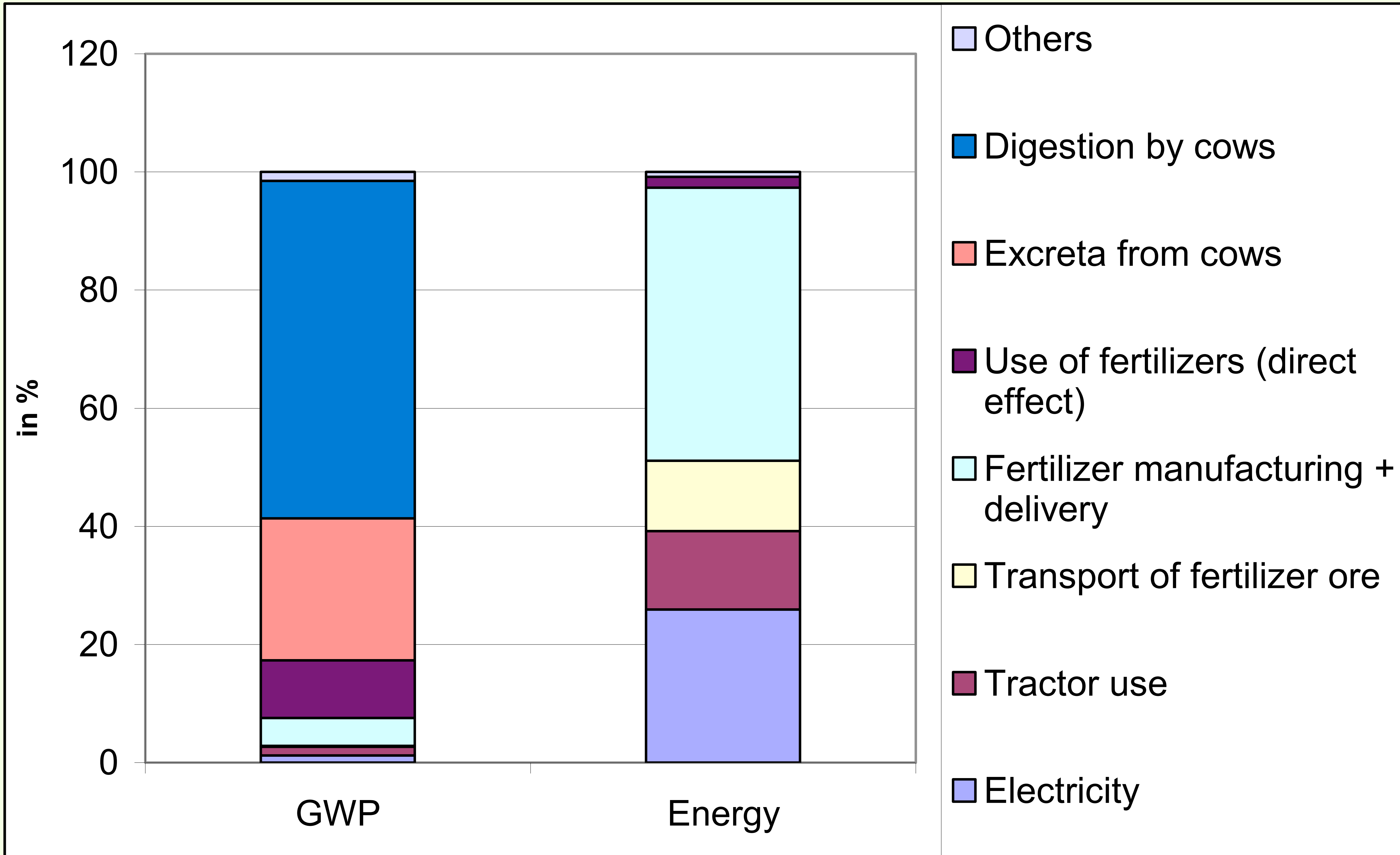
4th step: interpretation: comparing with other LCA studies

	Swedish Cederberg & Mattsson, 2000	German Haas et al., 2001	NZ This study
System boundary	Cradle to gate	Cradle to gate	Cradle to gate
FU	T ECM	T milk + ha on-farm grassland	T ECM + ha of land use
Allocation rules milk/meat	Biological (85/15)	None	Biological (85/15)
Studied farms	Experimental	Commercial	Average system
Production	Conv., organic	Conv. Int., conv. Ext., organic	Conventional
Impact categories	GWP, eutrophication, acidification, ecotoxicity, energy and land use	GWP, eutrophication, acidification, energy use	GWP, eutrophication, acidification, energy and land use

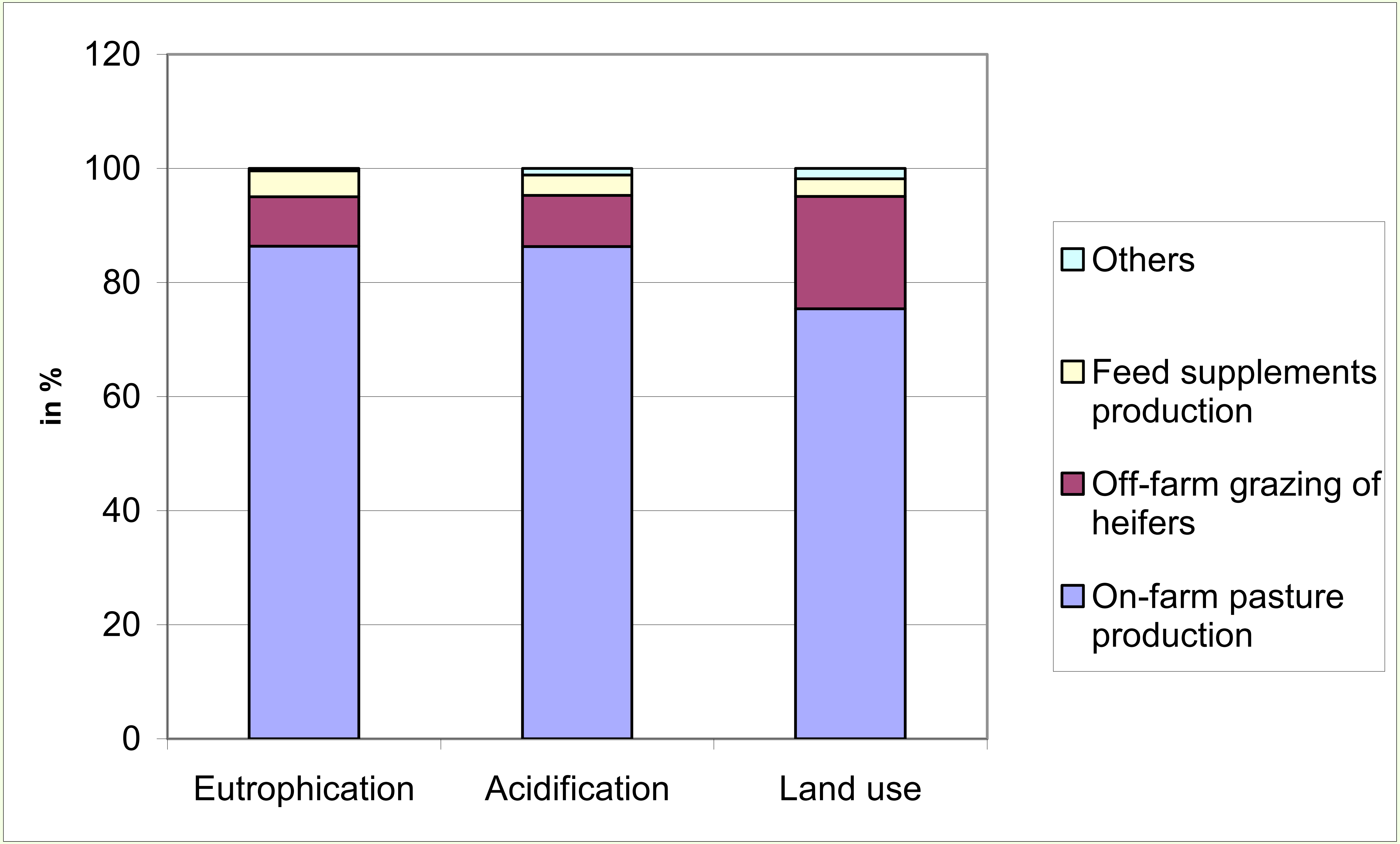
Comparative results…



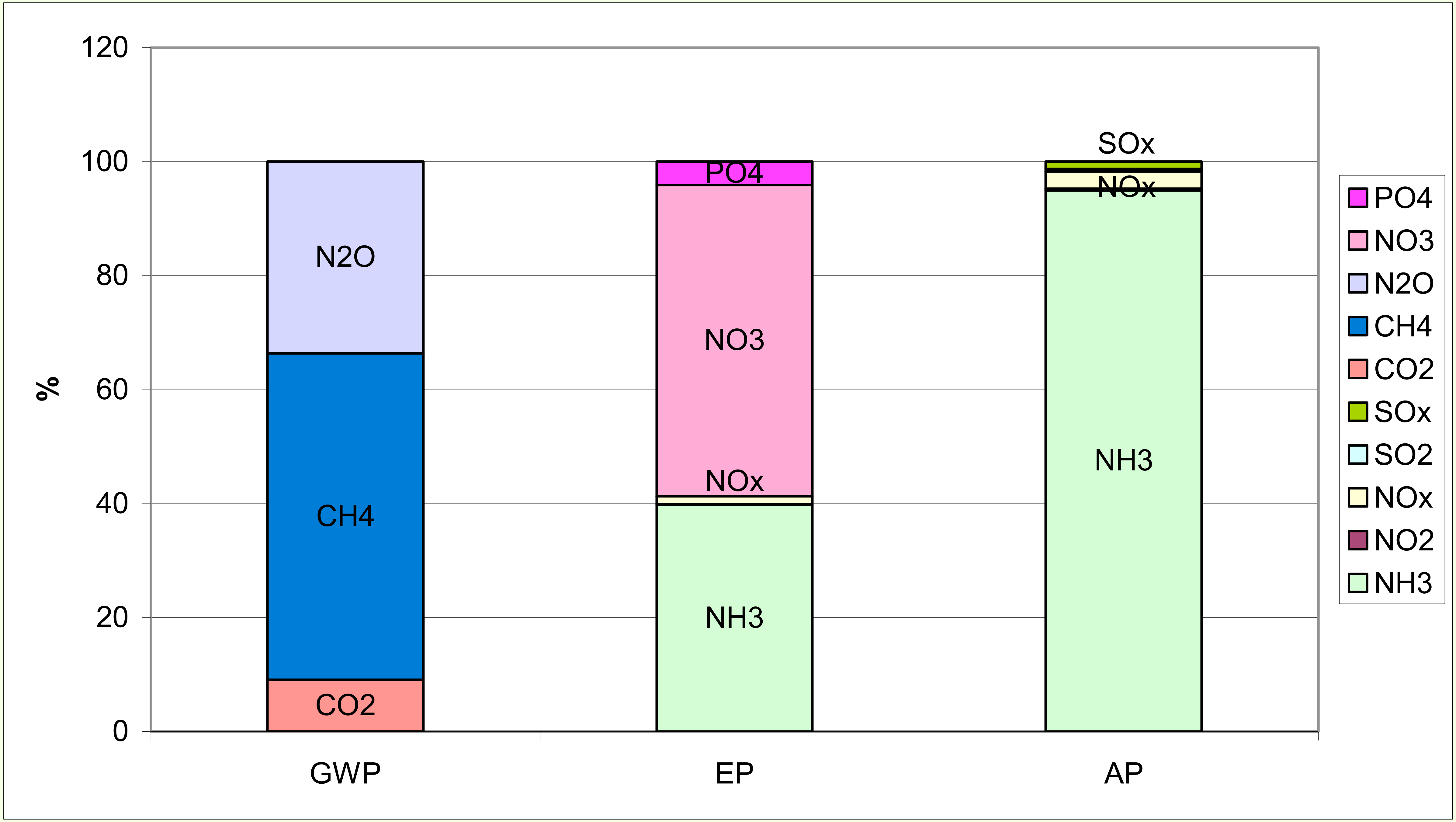
Contribution of the main processes of the NZ system to GWP and Energy use



Contribution of the main processes of the NZ system to eutrophication, acidification and land use



Contribution of main emissions to the impacts of the NZ conventional system



Areas of improvement for the current NZ average system?

➢Identification of hot-spots

- Improvement options (new technologies) should be focused on improving the system soil/pasture/cow
- And particularly on reducing N_2O, CH_4, NO_3 and NH_3

➢Research needs

- Uncertainty analysis
- Quantifying and reducing the main sources of uncertainty:
    - Estimates for the main emissions (N_2O, CH_4, NO_3 and NH_3)
    - Relevant characterisation models for regional impact categories in the NZ context

Life cycle assessment of conventional and organic milk production in the Netherlands

M.A. Thomassen et al. / Agricultural Systems 96 (2008) 95–107

General characteristics of the participating farms in the two pilot studies in 2003

Parameters	Units[a]	Conventional	Typical NL[b]	Organic	Typical NL[b]
Farms	n	10		11[c]	
Grassland	ha	35.5 (10.9)	29.9	40.7 (19.4)	36.1
Arable land	ha	11.2 (6.8)	8.6	11.5 (11.4)	10.8
Milking cows	n	81 (24.9)	63	71 (32.4)	56
Milk production[d]	kg/cow	7991 (800)	7630	6138 (980)	6390
Milk fat	%	4.41 (0.11)	4.42	4.45 (0.66)	4.40
Milk protein	%	3.44 (0.08)	3.49	3.44 (0.30)	3.45
Density	LU/ha[e]	2.13 (0.3)	2.31	1.70 (0.4)	1.76
Intensity	kg FPCM/ha	14713 (2342)		8937 (2655)	
Soil type		100% sand		45% sand 36% clay	
Diesel use on farm	L	4868 (2741)		5026 (3681)	
Electricity use on farm	kWh	27113[f] (12733)		28738[f] (18984)	
Purchased pesticides	kg active matter/ha	0.25 (0.10)			

[a] Units of parameters are given. Numbers for participating farms are means with standard deviation.
[b] Average values of a typical conventional and organic dairy farm in the Netherlands (Bintemet, 2003; CBS, 2003).
[c] Four farms were bio-dynamic.
[d] Milk with an economic value (e.g. delivered milk to the factory). Due to lack of data of private use of milk of some farms.
[e] LU = Dutch Livestock Units. 1 LU = the yearly phosphate excretion of one milking cow. Other animal categories are related to this LU.
[f] Five farms used renewable electricity.

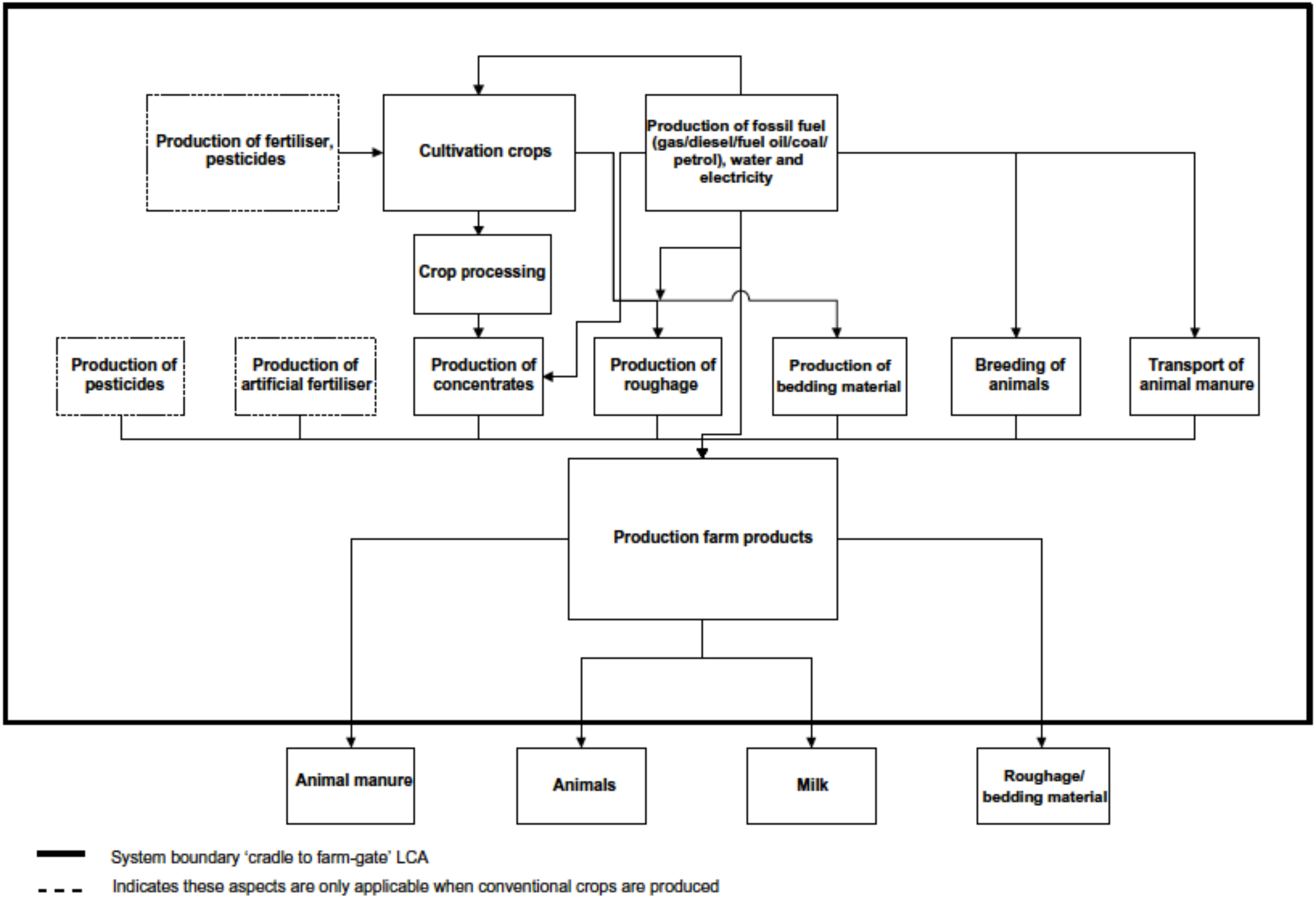


Fig. 1. System boundaries 'cradle to farm-gate' LCA.

Overview inventory data used in inventory analysis

	Element	Computation method[a]	Included factors	References[b]
Off farm[c]	Purchased pesticides	$Q*$ LCI/kg active matter	Production/ transport	Brand and Melman (1993)
	Purchased artificial fertilizer	$Q*$ LCI/kg artificial fertilizer	Production/ transport	Davis and Haglund (1999)
	Purchased concentrates	$Q*$ LCI/kg concentrates	Crop cultivation[d]	FAO (2002/2003), Cederberg (1998), CVB (2000)
			Crop processing	Brand and Melman (1993), Cederberg (1998)
			Transport	Cederberg (1998), Michaelis (1998), WPD (2003)
	Purchased roughage and bedding material	$Q*$ LCI/kg roughage	Crop cultivation	Dekkers (2001), LEI (2004), Koroneos et al. (2005)
			Transport	Cederberg (1998), Michaelis (1998)
	Purchased animals	$Q*$ LCI/animal	Breeding[e]	Tamminga et al. (2000), Oenema et al. (2000)
			Transport	Cederberg (1998), Michaelis (1998)
	Purchased animal manure	$Q*$ LCI/kg manure	Transport	Brand and Melman (1993)
	Contract work	$Q*$ LCI/litre diesel	Diesel use	Brand and Melman (1993), Hanegraaf et al. (1996)
On farm	Use of diesel	$Q*$ LCI/litre diesel	Supply and use	Michaelis (1998)
	Use of electricity	$Q*$ LCI/kW h electricity	Supply and use	Michaelis (1998), EnergieNed (2002), CertiQ (2003)
	Use of gas	$Q*$ LCI/m^3 gas	Supply and use	Michaelis (1998)
	Use of water	$Q*$ LCI/m^3 water	Electricity supply	Michaelis (1998), EnergieNed (2002)
On/off	Emissions of CH_4	Fixed values animals	Enteric + manure	Schils et al. (2006)
	Emissions of NH_3 and NO_x	Fixed values animals[f] and spreading of fertilizer	Stable/pasture/ deposit/spreading	Oenema et al., 2000, Van Geel (2004), Van der Hoek (2002), Mosier et al. (1998)
	Emissions of N_2O	Fixed values animals/soil	Direct and indirect	Mosier et al. (1998), Oenema et al. (2000)
	Leaching of NO_3 and PO_4	Farm-gate balance and soil surface balance	Net N-leaching factors	Schröder et al. (2005)
			Inputs and outputs	Van Eerdt and Fong (1998)

[a] Q is actual amount of product obtained from technical farm data. LCI is life cycle inventory, which is in most cases end values of a computation procedure.

[b] Most important sources used for the assessment of the life cycle inventory are given.

[c] Off farm includes upstream processes given in Fig. 1 until production farm products.

[d] For estimating related emissions and resource use for cultivation and processing of concentrates ingredients, more references were used than given in this table. For a detailed description we refer to Jansen (2005) and 's Gravendijk (2006).

[e] Breeding includes all aspects of growing-up: feed intake, emissions during stable period and pasturing.

[f] For milking cows ammonia emission and nitrogen excretion were related to milk urea (Van Duinkerken et al., 2005; Schröder et al., 2006).

Selected impact categories with related units, contributing elements and characterization factors[a]

Impact category	Unit	Contributing elements	Characterization factors	References
Land use	m^2	Land occupation	1 for all types of land use	Guinée et al. (2002)
Energy use	MJ	Energy consumption	1	
Acidification	kg SO_2-equivalents	SO_2	1	Heijungs et al. (1992)
		NH_3	1.88	
		NO_x[b]	0.70	
Climate change	kg CO_2-equivalents	CO_2	1	Houghton et al. (1994)[c]
		CH_4	21	
		N_2O	310	
Eutrophication	kg NO_3^--equivalents	NO_x[b]	1.35	Heijungs et al. (1992)
		P_2O_5	14.09	
		NH_3	3.64	
		NO_3^-	1	
		PO_4^{3-}	10.45	
		NH_4^+	3.6	
		COD[d]	0.22	

[a] Based on the Dutch LCA handbook (Guinée et al., 2002).
[b] NO and NO_2.
[c] Assuming a 100-year time horizon.
[d] Chemical oxygen demand; the amount of oxygen required to oxidize organic compounds in a water sample to carbon dioxide and water.

Results given in mean (standard deviation) of this LCA study of the conventional and organic milk production system given by impact category

Impact category	Unit		Milk production system		Significance[a]	Hotspot[b]	
			Conventional	Organic		Conventional	Organic
Land use	m^2/kg FPCM	On farm	0.64	1.1	**	Farm area	Farm area
		Off farm	0.64	0.7	–	C	C/R
		Total	1.3 (0.1)	1.8 (0.4)	***	Farm area/C	Farm area
Energy use	MJ/kg FPCM	Direct	0.6	0.96	*	D/G	D/E
		Indirect	4.4	2.17	***	C	C
		Total	5.0 (0.6)	3.1 (0.88)	***	C	C
Eutrophication	kg NO_3-eq/ kg FPCM	On farm	0.06	0.04	*	F	F/A
		Off farm	0.05	0.03	***	C	C/R
		Total	0.11 (0.01)	0.07 (0.03)	***	F/C	F/C/R
Acidification	g SO_2-eq/ kg FPCM	On farm	5.6	7.37	**	A/FA	A/FA
		Off farm	3.9	3.45	–	C	C/R
		Total	9.5 (0.8)	10.8 (1.9)	–	A/C	A/FA
Climate change	kg CO_2-eq/ kg FPCM	On farm	0.7	0.9	***	A/F	A
		Off farm	0.7	0.55	–	C	C/R
		Total	1.4 (0.1)	1.5 (0.3)	–	A/C	A/C/R

[a] $^*p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

[b] A = animals; C = concentrates; D = diesel; E = electricity; F = field; FA = fertilizer application; G = gas; R = roughage.

Results of two Swedish (Cederberg and Mattson, 2000; Cederberg and Flysjö, 2004) and one German (Haas et al., 2001) LCA studies compared with results of this Dutch study (Dutch'03) rounded to two digits

Case and year of data	Number of farms	Production system	Land use	Energy use	Climate change	Acidification		Eutrophication	
			m^2/t milk	GJ/t milk	kg CO_2-equivalents/t milk	kg SO_2-equivalents/		kg NO_3-equivalents/	
						t milk	farm ha	t milk	farm ha
Swedish'96	1	Conventional	1900	3.6	1080	18	130	61[a]	450
	1	Organic	3500	2.5	950	16	50	68	220
German'98	6	Conventional intensive	–	2.7	1300	19	140	78[b]	570
	6	Conventional extensive	–	1.3	1000	17	120	47	330
	6	Organic	–	1.2	1300	22	100	29	140
Swedish'01/'02	9	Conventional high	1500	2.6	900	10	–	39	–
	8	Conventional medium	1900	2.7	1040	10	–	43	–
	6	Organic	2900	2.1	940	12	–	52	–
Dutch'03	10	Conventional	1300	5.0	1400	10	140	108	1600
	11	Organic	1800	3.1	1500	11	100	67	600

[a] Eutrophication potential was given in O_2-equivalents and is transformed to NO_3-equivalents.

[b] Eutrophication potential was given in PO_4-equivalents and is transformed to NO_3-equivalents.

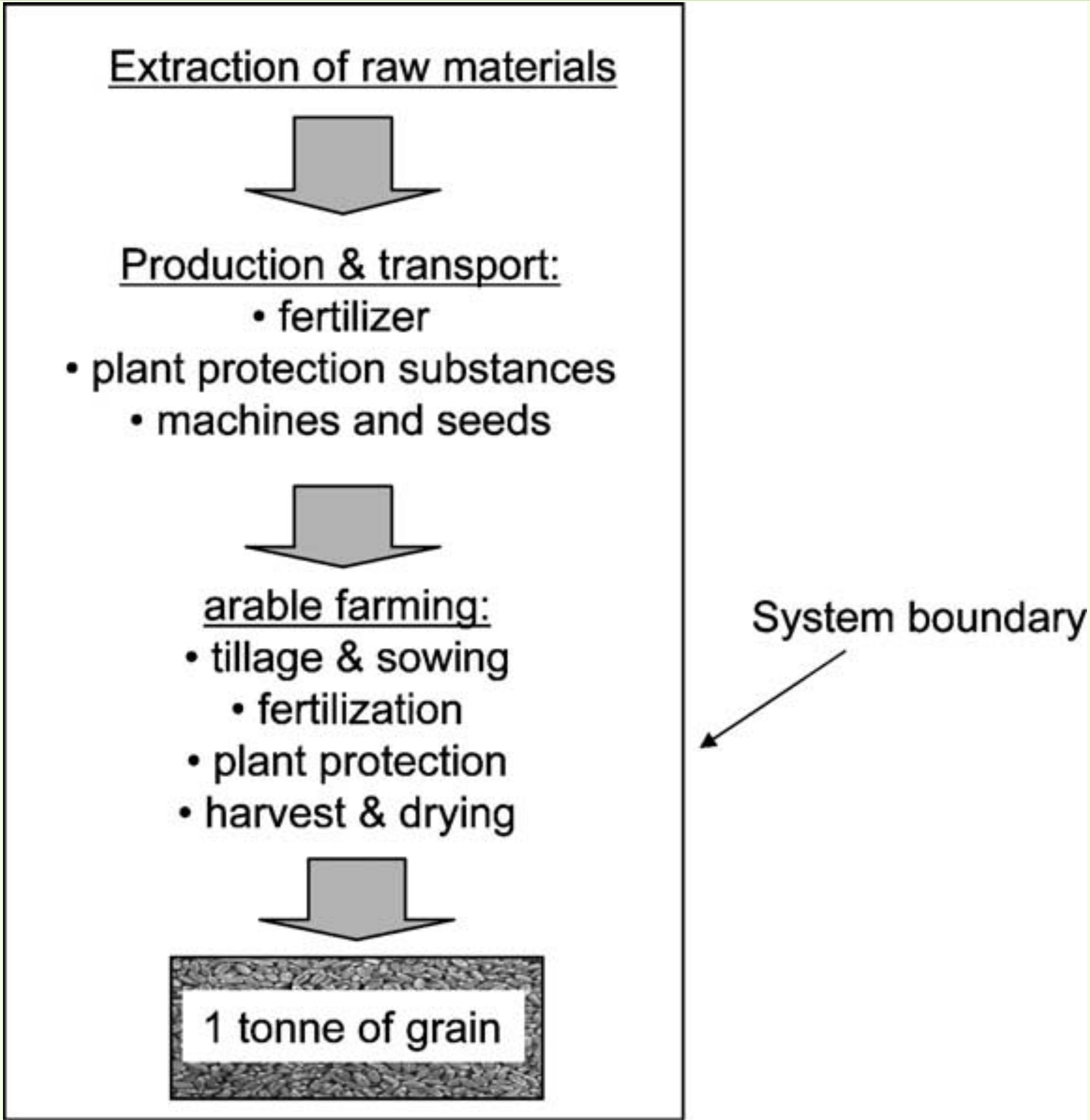
N fertilizer use in winter wheat production systems

F. Brentrup et al. / Europ. J. Agronomy 20 (2004) 265–279

A theoretical system based around the long established Broadbalk field experiment at Rothamsted (UK), complying with best management practices (BMP)

The Broadbalk wheat experiment

- The oldest continuously running field experiment in the world having been set up by John Bennet Lawes in 1843.
- compares the effects of different fertilizer treatments on the yield of winter wheat.
- In 1978, a five-course rotation was introduced (fallow, potatoes, 3 x winter wheat), which was modified in 1997 (winter oats, forage maize, 3 x winter wheat).
- In this LCA study, the average yield response of the 1st wheat in a rotation to increasing N fertilizer rates in the years 1996–2000 has been chosen to determine the productivity of the different N application rates.


Extraction of raw materials
Production & transport:
• fertilizer
• plant protection substances
• machines and seeds
arable farming:
• tillage & sowing
• fertilization
• plant protection
• harvest & drying
1 tonne of grain
System boundary

N fertilizer rates, average yields and nutrient removals for the wheat plots selected for the study

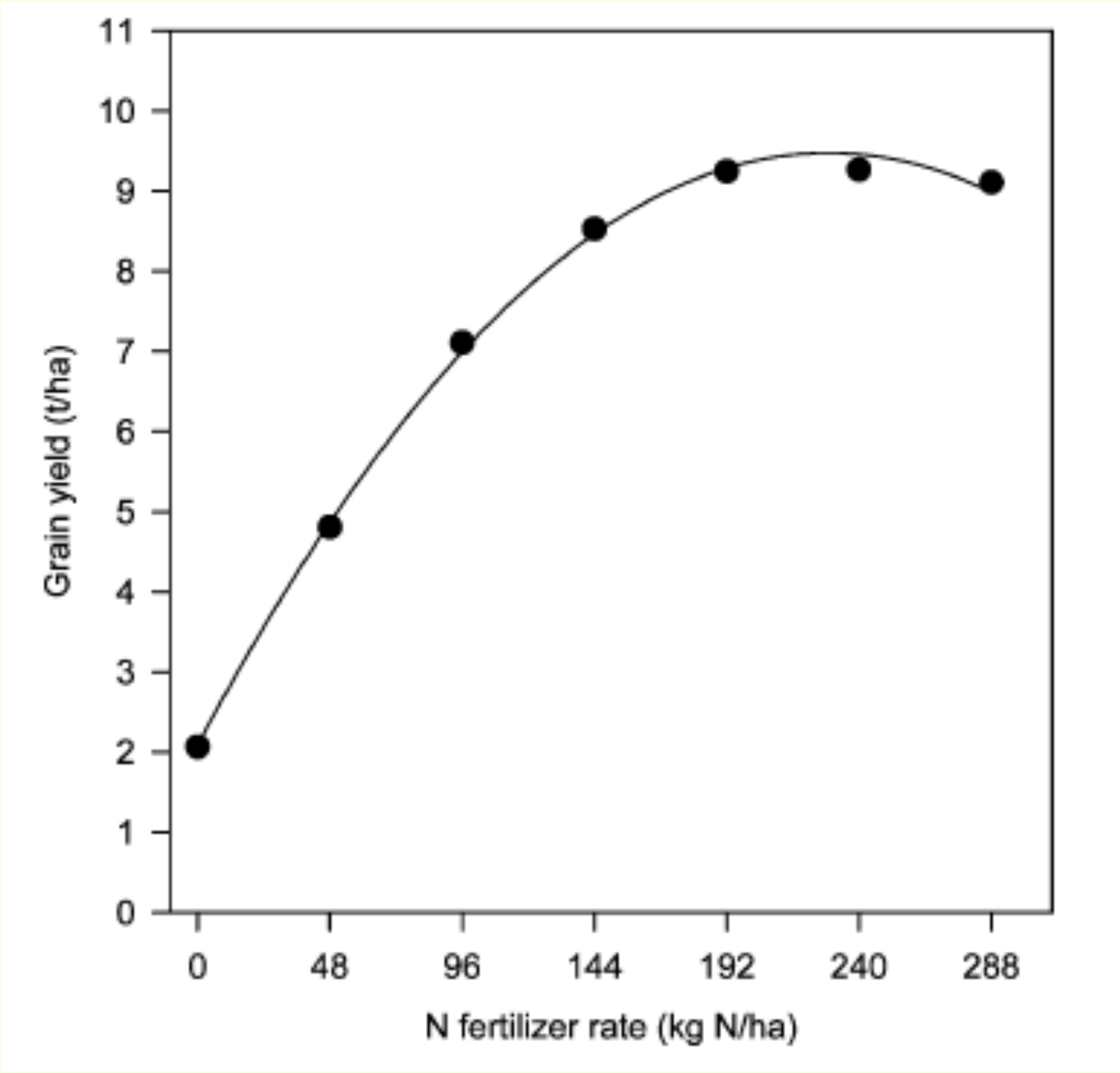
Fertilizer rates, yields and nutrient removal in the Broadbalk treatments

Plot number	N rate (kg/ha)	Yield (t/ha, 85% DM) [a]		Nutrient removal [b] (grain + straw, kg/ha)			
		Grain	Straw	N	P_2O_5	K_2O	MgO
N0	0	2.07	0.94	30	15	19	4
N1	48	4.81	2.55	64	36	48	9
N2	96	7.11	3.66	107	53	70	13
N3	144	8.53	4.35	147	63	83	15
N4	192	9.25	4.72	177	69	90	16
N5	240	9.27	4.96	196	69	93	17
N6	288	9.11	5.28	212	69	95	17

[a] Mean yield (1996–2000) for 1st wheat in the rotation (after potato or maize).
[b] Nutrient contents of grain and straw according to Poulton (2002, personnel communications).

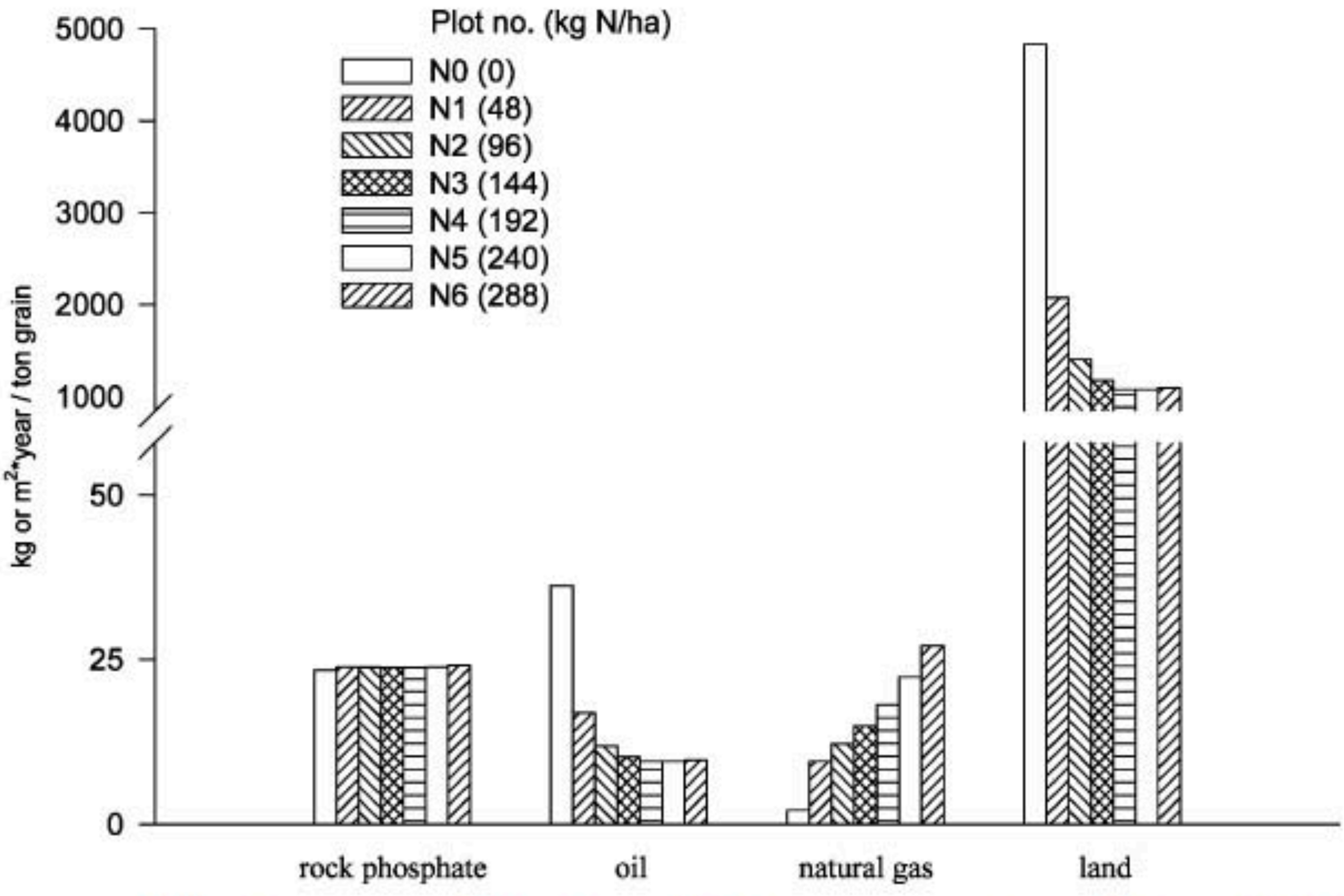
Only N rates, yields and nutrient content of grain and straw were directly taken from the Broadbalk field experiment.
The annual application of phosphate (P), potash (K) and magnesium (Mg) fertilizer is assumed, for the purposes of this study, to be according to crop removal (i.e. grain and straw) (Table 2).

Yield response of winter wheat to increasing N fertilizer rates (average for 1st wheat in rotation in 1996–2000).

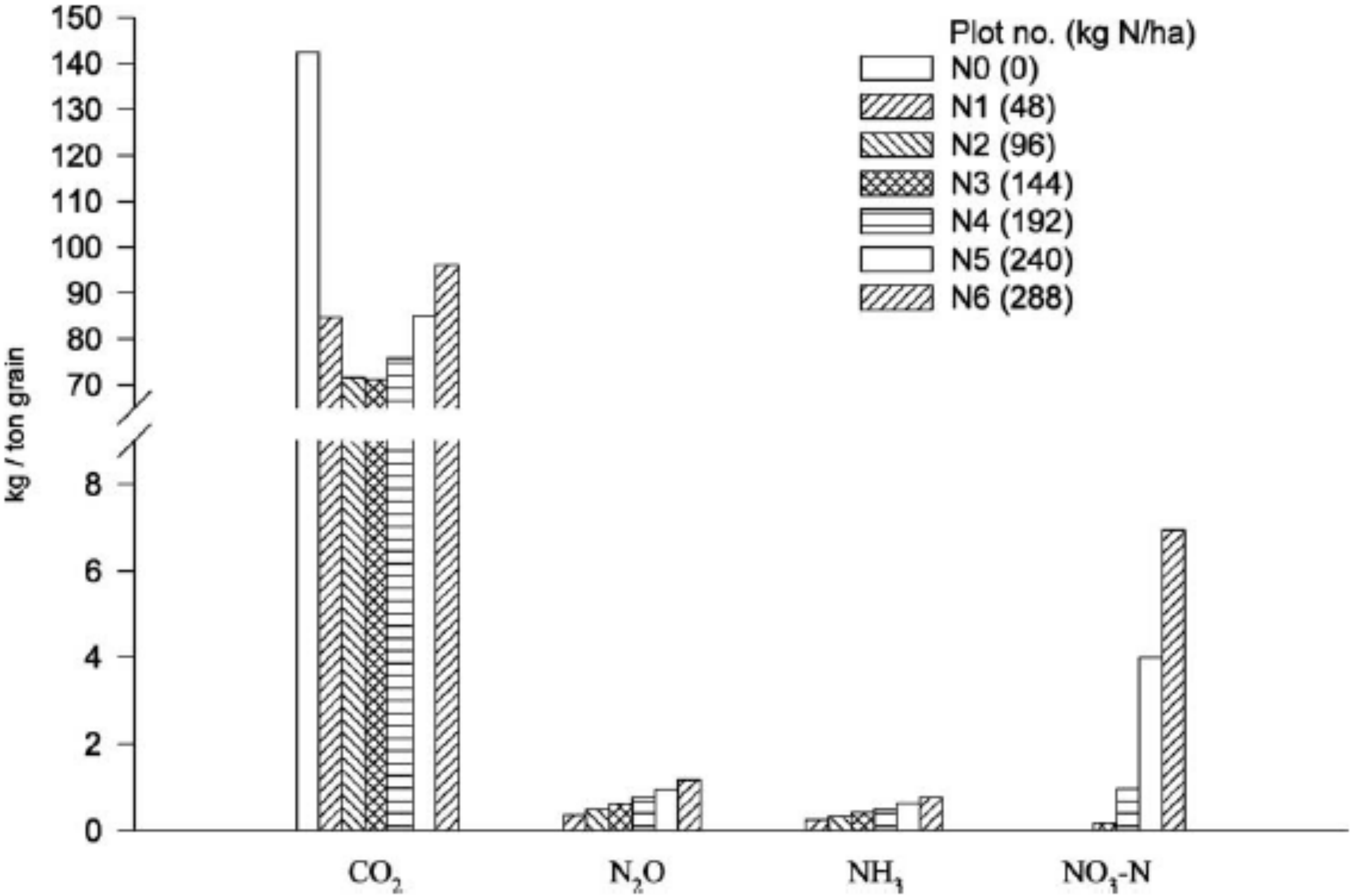


Environmental impact categories considered in the LCA on wheat production at different N application rates

Impact category
Depletion of abiotic resources (fossil fuels, phosphate rock, potash)
Land use
Climate change (= global warming)
Toxicity (human toxicity and eco-toxicity)
Acidification
Eutrophication (terrestrial and aquatic)



Consumption of P- and energy resources (kg) and use of land (m^2 year) per ton of grain at increasing N fertilizer rates.



Release of CO2- and N emissions per ton of grain at increasing N fertilizer rates

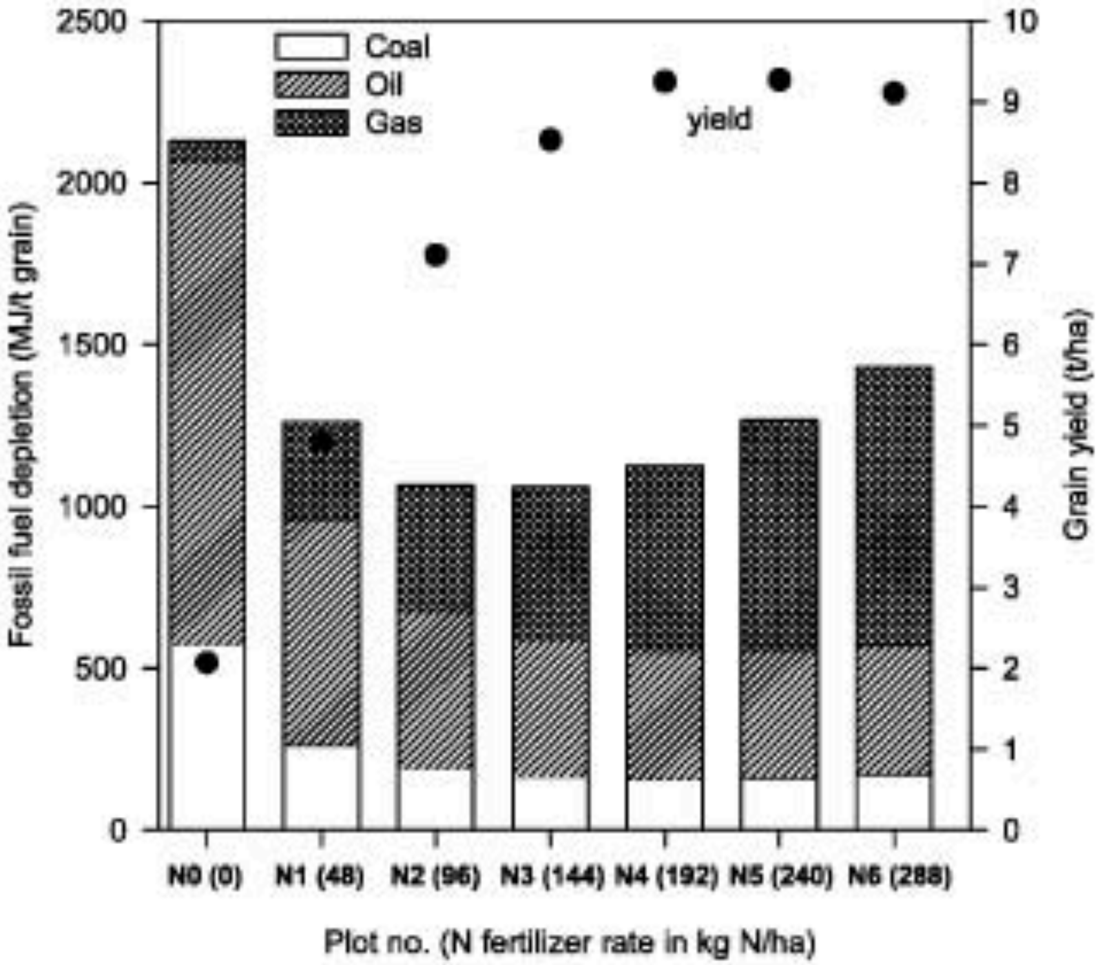


Fig. 5. Combined consumption of fossil fuels (MJ/ton grain, bars) and yields (t/ha, dots) at increasing N fertilizer rates.

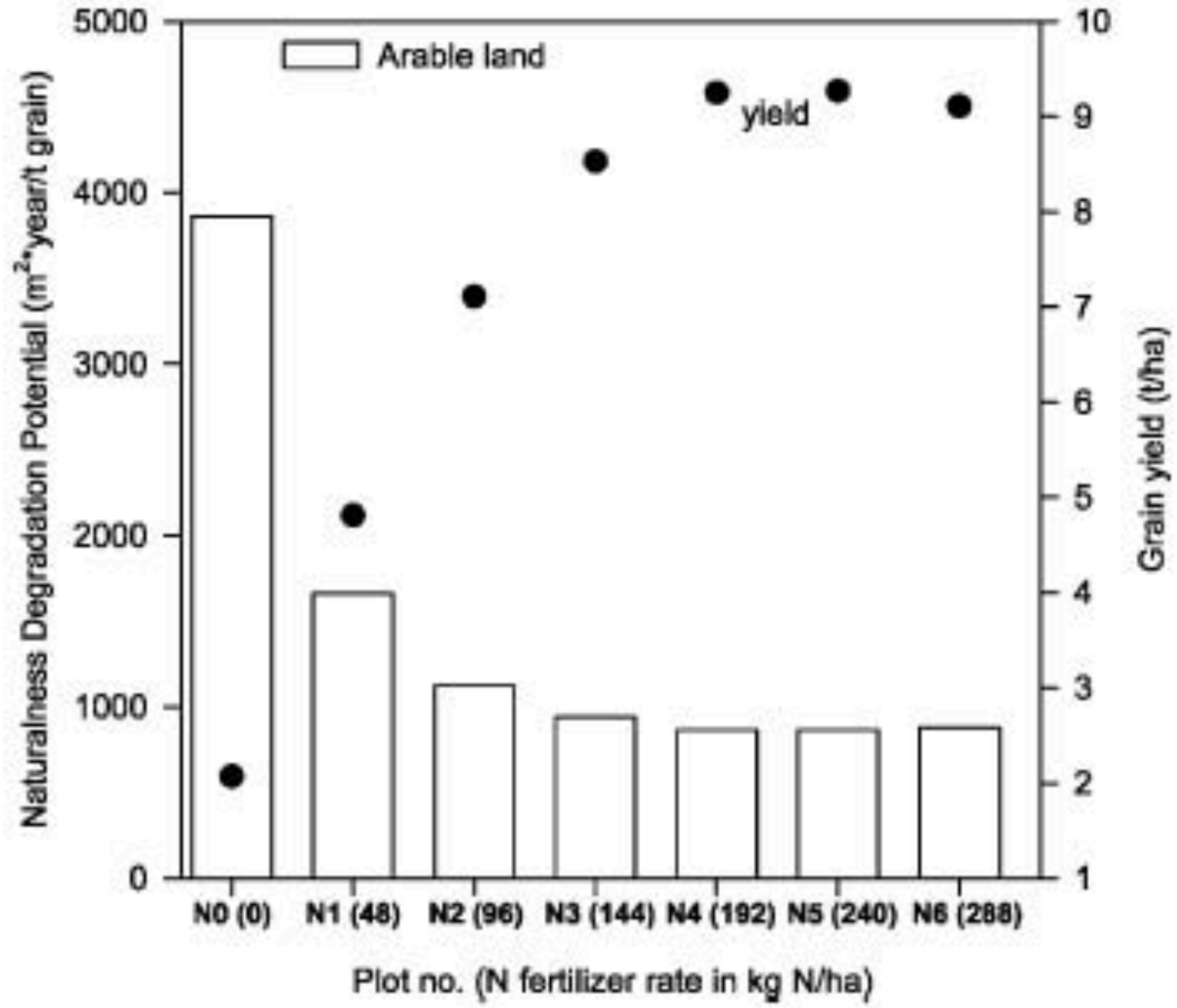


Fig. 6. NDPs ($m^2 \times$ year/ton grain, bars) and yields (t/ha, dots) at increasing N fertilizer rates.

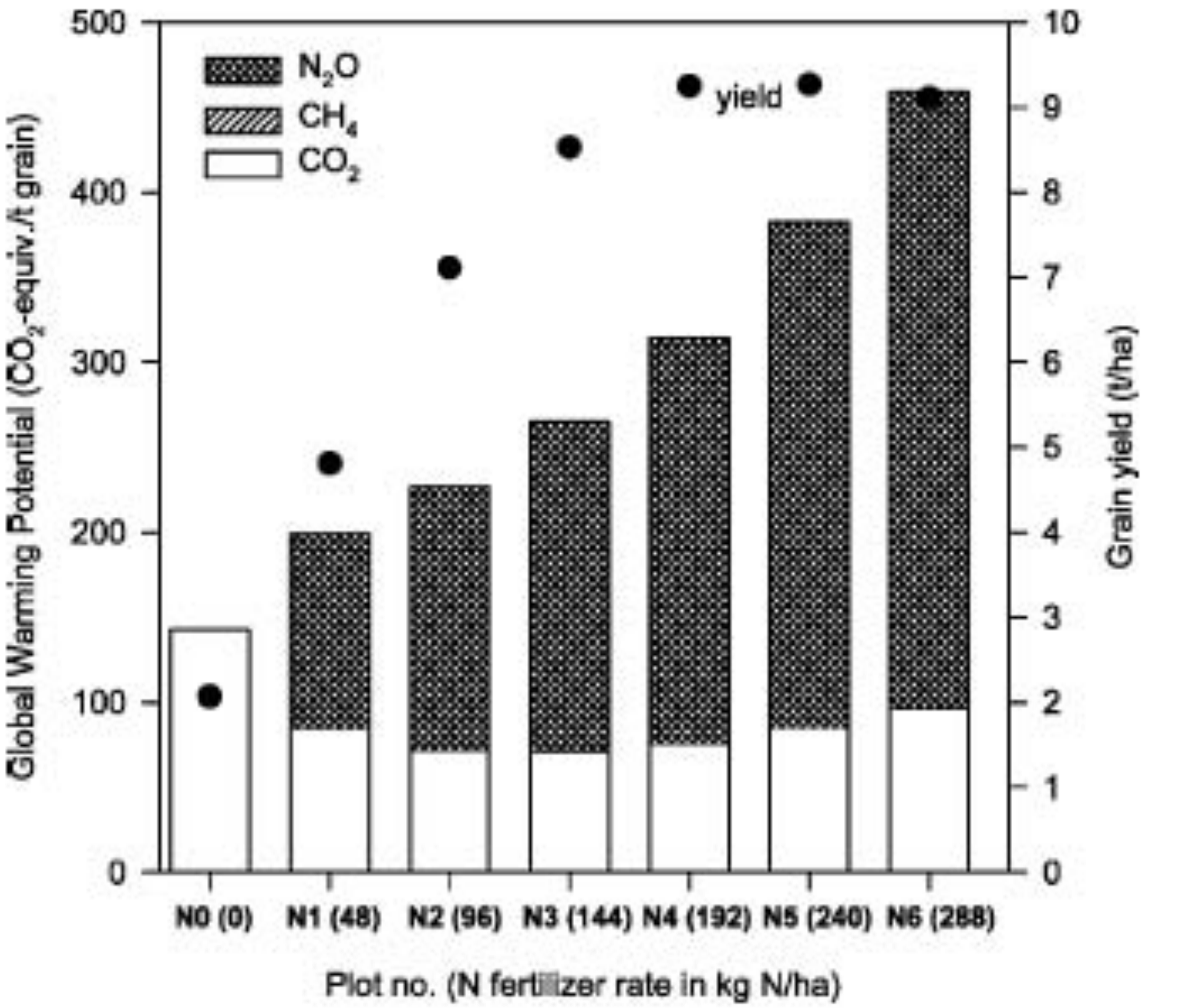


Fig. 7. GWPs (kg CO_2-equivalents/ton grain, bars) and yields (t/ha, dots) at increasing N fertilizer rates.

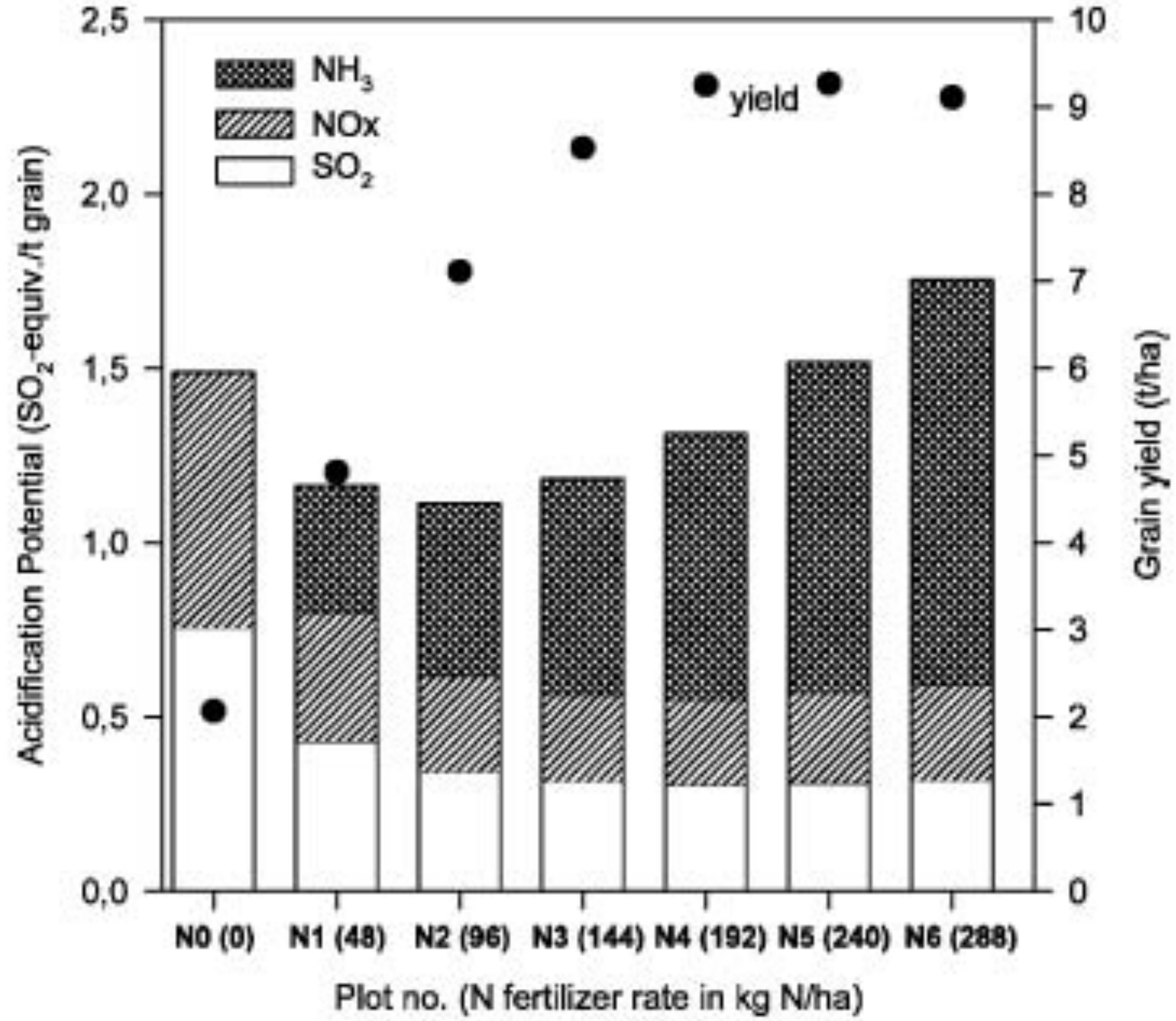


Fig. 8. APs (kg SO_2-equivalents/ton grain, bars) and yields (t/ha, dots) at increasing N fertilizer rates.

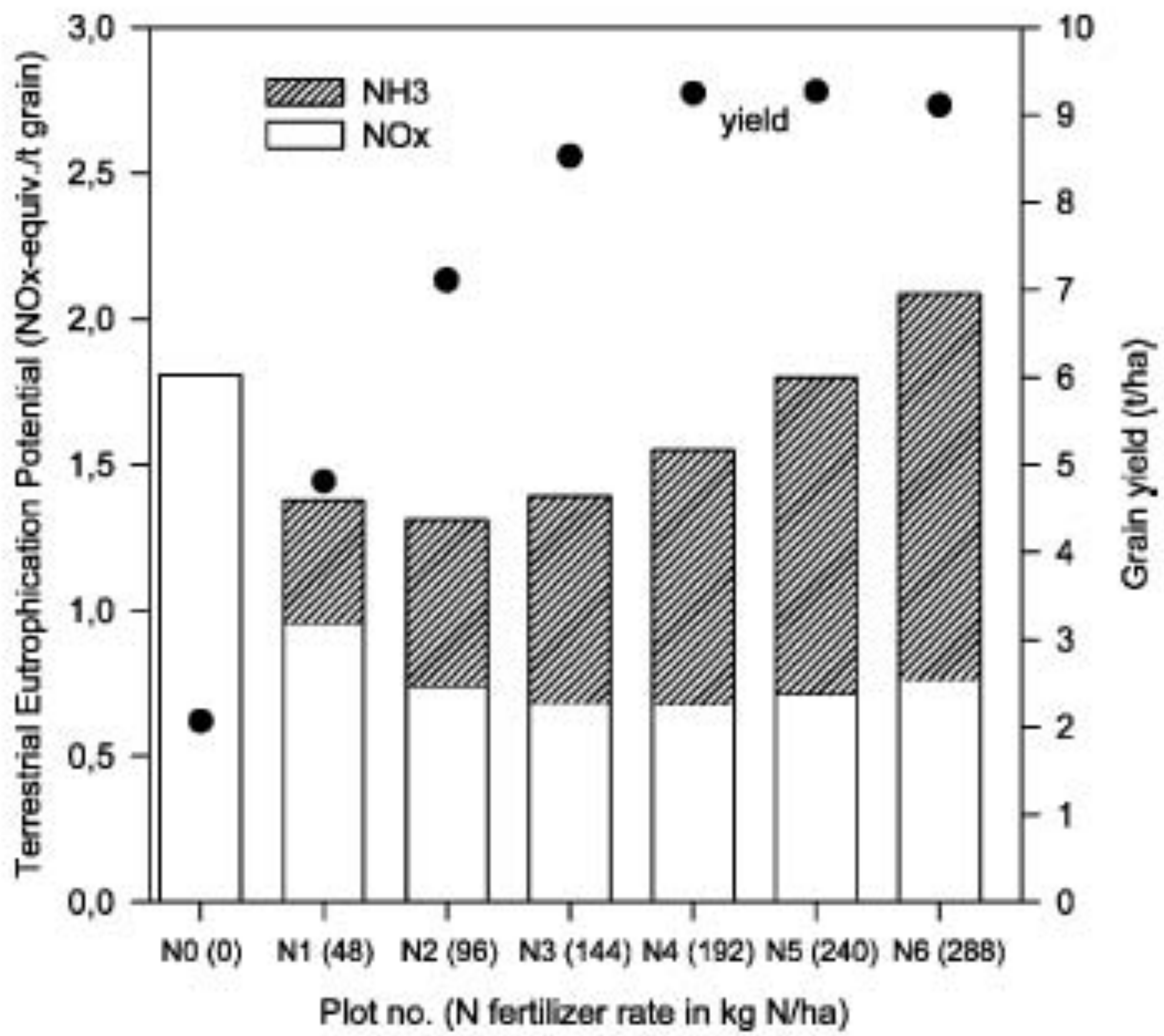


Fig. 9. TEPs (kg NOx-equivalents/ton grain, bars) and yields (t/ha, dots) at increasing N fertilizer rates.

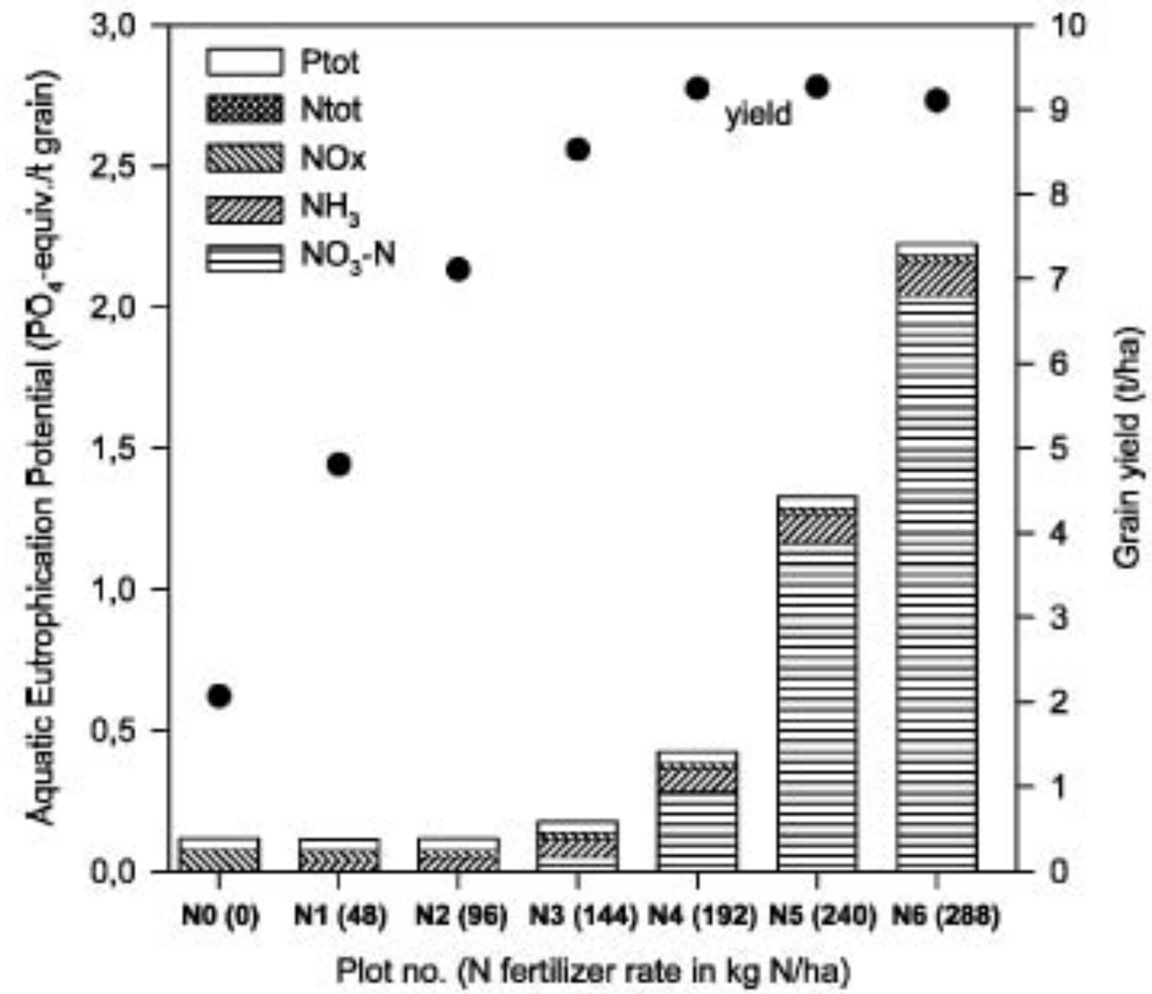
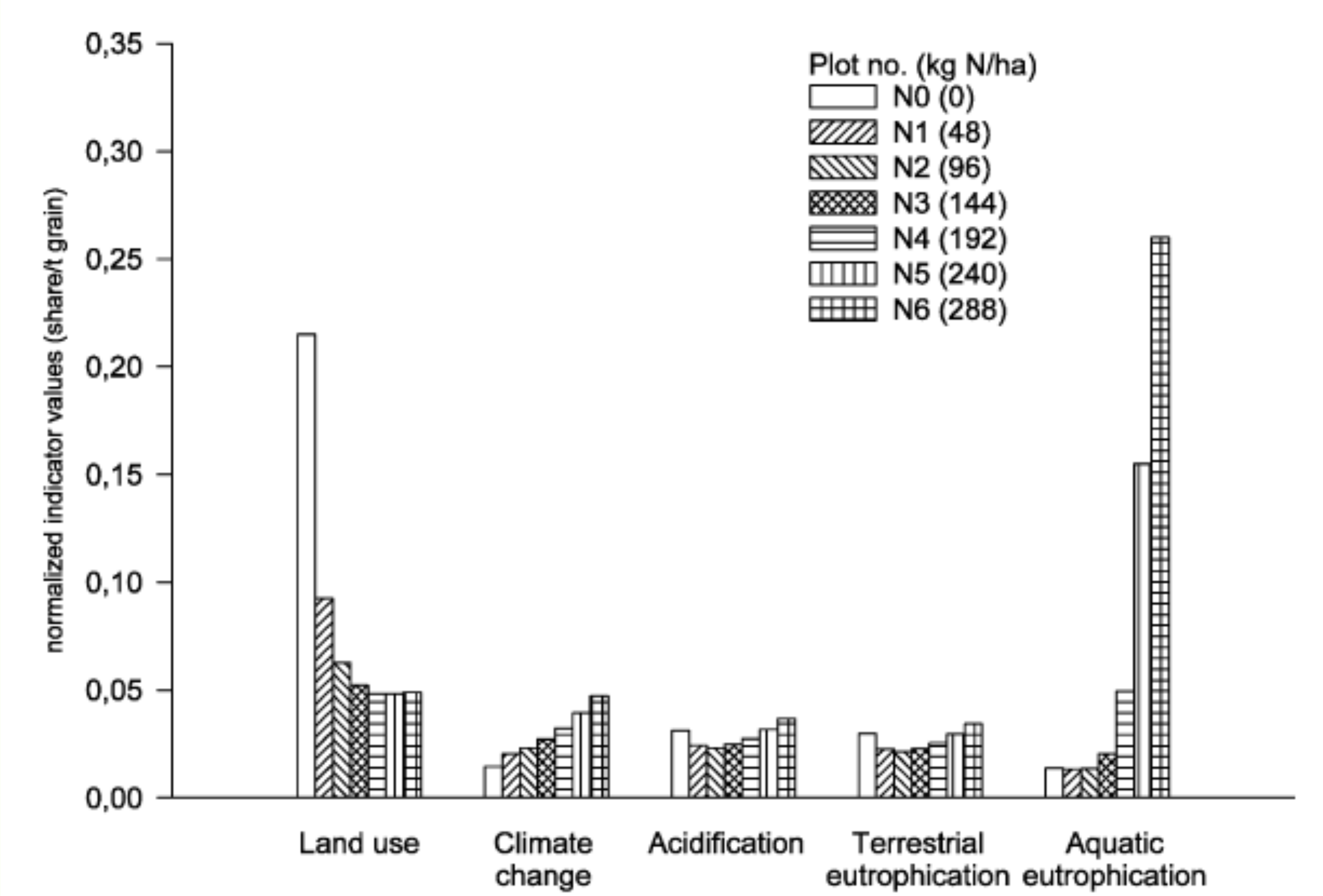


Fig. 10. AEPs (kg PO_4-equivalents/ton grain, bars) and yields (t/ha, dots) at increasing N fertilizer rates.

Contribution of wheat production at increasing N fertilizer rates to the depletion of phosphate rock, potash and fossil fuels (normalized indicator values per ton of grain)

Resource type	Plot number (fertilizer rate in kg N/ha)						
	N0 (0)	N1 (48)	N2 (96)	N3 (144)	N4 (192)	N5 (240)	N6 (288)
Phosphate rock	0.98	1.00	1.00	1.00	1.00	1.00	1.00
Potash	1.27	1.37	1.35	1.35	1.35	1.38	1.44
Fossil fuels	0.02	0.01	0.01	0.01	0.01	0.01	0.01

Contribution of wheat production at increasing N fertilizer rates to environmental effects per person in Europe



Weighting factors for the impact categories and data used for the calculation (current status, target value)

Impact category and impact sub-category	Indicator value (for unit see Table 10)		Basis for target	Weighting factor
	Current status (year)	Target value		
Abiotic resource depletion				
Lime consumption	1.16×10^{11} (1999)	–[a]	100 years availability[b]	0.00
Phosphate consumption	4.32×10^{10} (1999)	3.60×10^{10}		1.20
Potash consumption	2.56×10^{10} (1999)	8.40×10^{10}		0.30
Fossil fuel consumption	3.25×10^{14} (1999)	3.08×10^{14}		1.05
Land use				
Alpine region	8.84×10^{6} (1998)	8.84×10^{6}	Maintenance of current land use intensity in Europe[c]	1.00
Atlantic region	4.34×10^{7} (1998)	4.34×10^{7}		–
Black sea region	5.62×10^{5} (1998)	5.62×10^{5}		–
Boreal region	8.77×10^{6} (1998)	8.77×10^{6}		–
Continental region	7.71×10^{7} (1998)	7.71×10^{7}		–
Macaronesian region	2.30×10^{5} (1998)	2.30×10^{5}		–
Mediterranean region	4.40×10^{7} (1998)	4.40×10^{7}		–
Pannonian region	7.22×10^{6} (1998)	7.22×10^{6}		–
Steppic region	2.00×10^{6} (1998)	2.00×10^{6}		–
Climate change	3.50×10^{6} (1998)	3.32×10^{6}	UN-FCCC (1998)[d]	1.06
Toxicity				
Human toxicity, eco-toxicity	–	–	No target defined[e]	–
Acidification	1.42×10^{4} (1999)	1.06×10^{4}	UN-ECE/CLRTAP (1999)[d]	1.34
Eutrophication				
Terrestrial eutrophication	2.46×10^{4} (1999)	1.95×10^{4}	UN-ECE/CLRTAP (1999)[d]	1.26
Aquatic eutrophication	1.10×10^{6} (1995)	8.07×10^{5}	OSPAR (1995)	–
HELCOM (2001)[f]	1.37	–		–

[a] No problem expected due to very large lime reserves (USGS, 2001).

[b] Target based on assumption that an availability of the resource for at least 100 years is sufficient for the development of substitution or recycling techniques (Brentrup et al., 2002a).

[c] Target based on the assumption that the current land use intensity in each biogeographic region of Europe is tolerable and should be maintained (Brentrup et al., 2002b).

[d] Values based on emission rates and reduction targets for Western European countries.

[e] Only separate targets for specific groups of toxic substances (e.g. heavy metals to air), but no overall international target for the reduction of toxic emissions available.

[f] Values based on emission rates and reduction targets for Western European signatory states of OSPAR and HELCOM conventions.

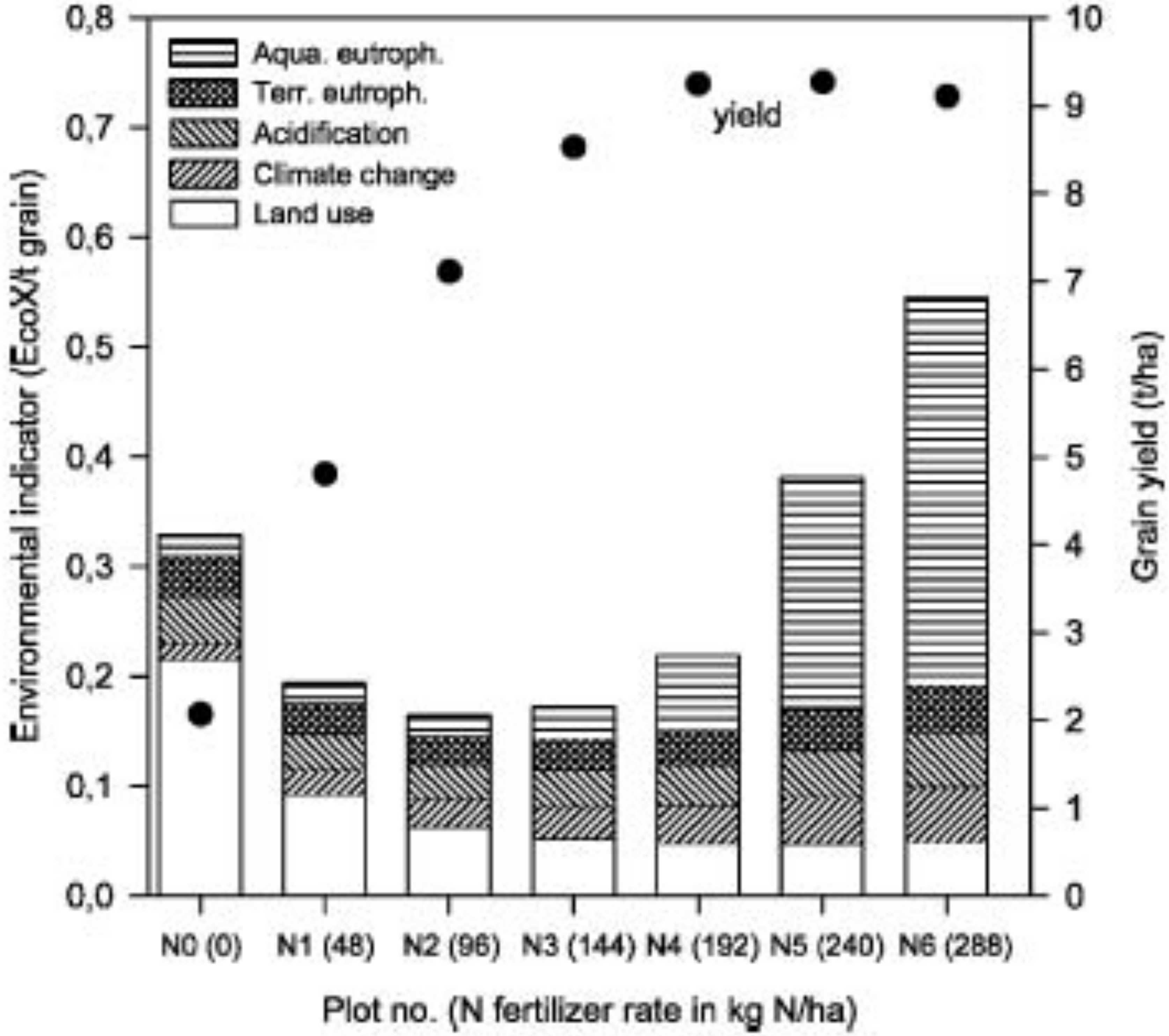


Fig. 12. Aggregated environmental indicator values (EcoX) per ton of grain (stacked bars) and yields (t/ha, dots) at increasing N fertilizer rates.

From this LCA case study, it can be concluded that a good environmental performance in wheat production can be achieved by:

1) Maintaining optimum yields, in order to use land most efficiently.

2) Applying nitrogen according to crop demand, in order to minimize NO_3 leaching.

3) Using nitrogen fertilizers with low NH_3 volatilization rates (e.g. AN), in order to keep acidification and terrestrial eutrophication low.

4) Reducing N_2O emissions during nitrate fertilizer production (scrubbing techniques), in order to reduce the GWP.